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MINUTES OF PROCEEDINGS

OF

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THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. CIII.

EDITED BY

JAMES FORREST, Assoc. Inst. C.E., Secretary.

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CORRIGENDA.

Vol. cii. p. 75, Fig. 1, *for* "Scale of revolutions *at*, &c.," *read* "Scale of revolutions *and*, &c."
„ p. 90, line 5 from bottom, *omit* "Appendix."
„ p. 122, line 22, *for* "Fig.," *read* "Table."
„ p. 151, line 21, *for* "p. 78," *read* "p. 76."
„ p. 389, line 11 from bottom, *for* "Rude*llof*," *read* "Rude*loff*."
„ p. 394, line 6, *omit* "*v*" from the formula. It has been pointed out that a preferable expression would be $HP. = \frac{G^2 \times D \times R}{1,000}$.
„ p. 403, line 30, *for* "25,549," *read* "28,549."
„ p. „ line 3 from bottom, *for* "14,387," *read* "14,337."
Vol. ciii. Plate 8. The Sectional Elevation should have been Fig. 12, and the Section on line E F, Fig. 12*a*.

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1890-91.—PART I.

SECT. I.—MINUTES OF PROCEEDINGS.

11 November, 1890.

SIR JOHN COODE, K.C.M.G., President,
in the Chair.

PORTRAIT OF THE SECRETARY.

Sir JOHN COODE, President, said he claimed the indulgence of the members while adverting for a moment to a subject extraneous to the usual course of proceeding. As time had gone on, the Council had felt how valuable—indeed, he might rather say how invaluable—had been the services rendered to the Institution by its Secretary, Mr. Forrest. As the outcome of that feeling it had been suggested at the Council table that expression could be best given to it by having Mr. Forrest's portrait painted and placed in the Institution. To say that that suggestion was cordially received would be but a very mild way of describing it. As the members would well understand, it was received with the utmost enthusiasm. Only those who had sat at the Council table could form anything approaching a correct idea of the services which the Secretary had rendered to the Institution. He could go a step further, and say—and in saying it he was sure that he should be borne out by every Past President—that until a gentleman had occupied the presidential chair, he really was not in a position to form a truly adequate conception of the manner in which Mr. Forrest fulfilled his duties. In that view the Council had decided that the portrait should be presented as a gift from themselves as a body—that it should be limited to the President, Past Presidents, and Members of the Council of the Institution. Had it been otherwise, he was quite sure that they would have been flooded with requests to join in that tribute of respect. The picture had been painted. Mr. Forrest,

of course, knew that it was being done—indeed, he had a very painful knowledge of it. He (Sir John Coode) had often come into the room whilst the artist was at work, and if he had admired Mr. Forrest's patience before, he admired it much more when he saw the ordeal that he was undergoing. It was not, however, until within a few hours that Mr. Forrest knew at whose instance the portrait had been painted and by whom it had been presented. He could add very much more, and would do so, but for Mr. Forrest's presence. If he understood anything of Mr. Forrest's nature, he was sure that he would wish him to stop and say nothing further. The agreeable duty now devolved upon him—and he regarded it as exceedingly fortunate that it had fallen to his lot as President of the Institution to act as the mouthpiece of the Council on that occasion—of offering in their name for the acceptance of the Institution the portrait of Mr. Forrest which was now on the easel before them.

Mr. James Forrest said the President had imposed upon him a most difficult task. Sir John had rightly gauged his feelings in abstaining from saying anything more in his praise. For the kindly words to which the President had given utterance, and for the sympathetic manner in which they had been received, he desired to return his most grateful thanks. He could never, in the wildest freak of imagination, have supposed that the Council and the members of the Institution would desire to retain permanently within the walls his own personality. The honour conferred upon him was all the greater as coming from the governing body, to whom, as the President had remarked, the Secretary and his character must be much better known than to any ordinary member. The greater part of his life had been spent within those walls, and those who knew him best would believe him when he said that the chief happiness of his life had been to witness the prosperity and usefulness of the Institution. He could not trust himself to say more, but he thanked them most sincerely.

Distribution of Premiums.

The President then proceeded to distribute the Medals, Premiums, Miller Scholarship, and Miller Prizes awarded by the Council for the Session 1889–90 (vol. cii. pp. 194, 204).

(*Paper No. 2469.*)

"Steam on Common Roads."

By JOHN McLAREN, Assoc. M. Inst. C.E.

THE history of the rise and development of the use of steam on common roads was exhaustively dealt with in a Paper by the late Mr. John Head, read before the Institution in 1873.[1] The Author therefore intends to pass over the difficulties and failures of the earlier makers of traction-engines, and to proceed at once to the consideration of the position which steam now holds as a motive power for working heavy traffic on ordinary roads.

The multiplication of tramways in towns, for which a special class of locomotive is constructed, and the difficulties opposed to the use of steam-engines on roads by the legislature, have prevented the adoption of traction-engines to any extent for the conveyance of passengers, and their use is now practically confined to agricultural work, such as threshing and steam-ploughing, and to the conveyance of merchandise and heavy traffic, which cannot be so readily dealt with by animal power.

During the last twenty years the many different designs and modes of construction dealt with in Mr. Head's Paper have been put to the test of practical experience, which has shown that the most practicable and efficient road-engines are those which most nearly approach in design and appearance to what may be called the locomotive pattern. The details of construction, however, must be varied to suit the different conditions under which traction-engines are required to work, and the legislative restrictions under which they are placed. They must be constructed so as to turn the acute angles which are sometimes encountered both in country roads and in the streets of large towns. The roads over which they are required to travel have gradients up to (and frequently exceeding) 1 in 10; they may be paved with smooth and slippery setts, or coated with new road metal; they vary in hardness and slipperiness according to the state of the weather; and at times they are so badly constructed that the engine wheels cut through the thin crust of macadam, and sink into the soft ground beneath.

[1] "On the Rise and Progress of Steam Locomotion on Common Roads." By John Head. Minutes of Proceedings Inst. C.E., vol. xxxvi. p. 36.

Amongst the legal restrictions may be mentioned, first, that such engines have been held to be a nuisance at common law. Secondly, that in nearly every case the owner is obliged to obtain a license from a Court of Quarter Sessions, to enable an engine to travel on any highway; and that he may have to wait nearly three months before such license can be granted; that this license, though it is evidence that the engine is constructed in accordance with the requirements of the Act of Parliament, affords the owner no protection whatever against any person or public body raising the most frivolous objections to the passage of the engine. Thirdly, that in country districts, though there may be no other traffic on the road, the speed of the traction-engine is limited to 4 miles per hour, and a man is required to walk in front, at a distance of not less than 20 yards. Fourthly, that the road-authorities have an almost arbitrary power to forbid the use of certain bridges by such engines, though the bridges themselves may be of ample strength to carry the weight without danger; and further, that although damage done to a bridge by the passage of heavy castings, or other weights drawn by horses, is made good at the public expense, such damage must be made good by the engine-owner, in case the same load should happen to have been drawn by a traction-engine. Fifthly, that certain urban authorities have been allowed to embody in their Local Acts clauses by which they are able to prohibit the use of traction-engines on any street or road within their jurisdiction.

These, and other hindrances, added to the mechanical difficulties connected with working steam-engines on common roads, account in a large measure for the comparatively slow progress in this country of this method of traction. No doubt, if artificial barriers were removed, the system would soon be largely developed, to the great advantage of the community.

In spite of all these difficulties, thousands of traction-engines are in daily use, and a number of firms make a specialty of their manufacture. The following description, with slight variations in detail, applies to the engines of all the leading makers.

The multitubular type of boiler, horizontal cylinders, and the link-motion reversing-gear are almost exclusively adopted. In order to reduce the weight of the engine, all separate framing is dispensed with as far as possible, the cylinders and various working parts being bolted direct upon the boiler (Fig. 1), which is constructed with a sufficient margin of strength to resist the additional strains from the machinery. It is usual to transmit the power of the engine from the crank-shaft to the main axle

through a train of gearing, which not only enables a comparatively small engine to exert a great tractive force, but also facilitates the use of large driving-wheels, and at the same time reduces the speed at which the engine can travel to that prescribed by law.

As a rule, the cylinder is placed on the forward end of the boiler near the chimney. It is generally cast within a steam-dome, which forms a jacket, whence it derives a constant supply of dry steam, so that the tendency to prime is overcome. The steam-regulator and throttle-valve may be contained in the same casting, and the safety-valves may be conveniently placed on the dome-cover. The steam-chest cover should be so situated that it can be removed for examining the slide-valve while steam is up. The crank-shaft is generally fixed at the fire-box end, the intermediate shaft crossing the boiler-front just over the fire-door, and the main axle being directly underneath the intermediate shaft, and generally below the foot-plate between the fire-box casing and the water-tank.

The late Mr. Thomas Aveling, M. Inst. C.E., designed a very simple, light, and effective arrangement for carrying all the bearings for these various shafts. This consisted in prolonging the plates forming the sides of the outer shell of the fire-box both upwards and backwards; bolting the crank-shaft brackets to the upper projections of these side-plates, and those for the intermediate shaft and main axle to their backward projections. All the shafts were thus kept in position, and the gearing could not get out of pitch except by excessive wearing of the bearings, or by tearing of the plates.

The boiler-pressure ranges from 80 lbs. to 170 lbs. on the square inch, but the average working pressure may be taken as 130 lbs. The boiler must be well made, for in addition to the internal pressure, it has to stand the racking strain caused by the working of the engine, and shocks resulting from the rough jolting over bad and uneven roads.

The boiler-shells are generally made of Siemens-Martin mild steel, with a strength of from 27 to 30 tons per square inch, and an elongation of about 25 per cent. in 6 inches. The circular seams are single-riveted, and the longitudinal seams are double-riveted. Butt-joints are seldom met with. The fire-boxes are generally made of best Yorkshire iron, or mild steel, and the tubes of wrought-iron, lap-welded. These are swelled $\frac{1}{8}$ inch at the front end, and can therefore be easily withdrawn for scaling or renewal. So far as the experience of the Author is concerned, the most satisfactory material for the construction of traction-engine fire-boxes is mild steel. Solid iron fire-box foundation-

and fire-door-rings are now used in preference to Z-iron rings. The water-space around the fire-box varies in width from about 2¼ inches as a minimum at the bottom to 3 or 4 inches at the top, thus giving a good circulation where it is most needed.

The recent improvements in the manufacture of steel castings have been of great service to the builders of traction-engines. This material is now almost exclusively used for the spur-gearing transmitting the power of the engine to the main axle. The wheels can thus be made of extraordinary strength without excessive weight. This gearing is arranged so as to give a choice of two speeds upon the road, viz., about 2 or 4 miles per hour, the latter being the maximum speed allowed by the present Acts of Parliament. The driving wheels of every traction-engine should be fitted with differential or compensating gear, to enable them to turn sharp curves without any great loss of power, and without unduly straining the axle by the surging or slipping of the inside wheel. This compensating gear consists of a pair of strong cast-steel bevel wheels, A B, Fig. 2, disposed face to face, the one A keyed firmly upon the axle C, the other B secured to the boss D of one of the road wheels, which is mounted loosely upon the axle. Two bevel-pinions, E E, are mounted upon pins, or studs carried between the aforesaid bevel-wheels, the teeth on one side of the pinion gearing into one bevel-wheel A, and those on the other side of the pinion gearing into the other bevel-wheel B. This is a modification of a well-known movement which was first employed in White's dynamometer, and published in his "Century of Inventions" sixty-eight years ago, and it is now largely used where a differential movement of road-travelling wheels is required, such as in traction-engines, tricycles, &c.

In connection with the gearing of a traction-engine a most valuable feature is the winding-drum F, which is generally fixed on the main axle, between the road wheel and the fire-box casing. By an arrangement of pins G, the road wheels may be thrown out of gear, and the winding-drum made to revolve upon the main axle, without moving the engine (Fig. 2), in which the winding-drum and differential gear are combined. The whole power of the engine may thus be concentrated upon this small drum, round which a steel cable may occasionally be used with great advantage. For instance, the engine may be loaded with a heavy casting or other weight, up to the limit of its power with the slow gear. It may be able to haul this load on ordinary roads where there are no heavy gradients; but quite unable to mount with it up a steep hill. In the latter case the

engine would be detached, and moved to the top of the hill, the load being left at the bottom; the road wheels would then be thrown out of gear, and firmly "scotched," and the rope or cable would be made fast to the load, which could then be wound to the top of the hill with the greatest ease. It is evident that this arrangement of drum and rope may be made to serve a variety of useful purposes.

The crank-shafts are usually bent out of a round bar of mild steel, with collars welded on to form the journals. The intermediate shaft and main axle are usually forged of the same material.

The road-travelling wheels are variously made, the simplest form consisting of cast-iron rim and boss (Fig. 3), with wrought-iron spokes, the ends of which are cast within both the rim and the boss, and with wrought-iron or steel cross plates riveted on the face of the rim. A better wheel is made by putting two rings of wrought-iron tee-bar (welded and blocked to a true circle) side by side (Fig. 4), either with a wrought-iron cover plate and wrought-iron or steel cross plates riveted on as at H, or with the cross plates riveted directly to the tee-bars as at I. In either case the boss of the wheel is cast around the wrought-iron tee-headed spokes which have been previously placed in position in the sand. Holes are drilled through the spoke-heads and the tongue of the tee-bar, which are then firmly riveted together by powerful machinery.

The best arrangement for the fore carriage consists in mounting the front axle beneath a cast-iron bearing, which forms a sort of turntable, supporting the front end of the boiler. The axle is carried beneath by a horizontal pin, upon which it rocks, so that there is a sort of universal joint under the front end of the engine, permitting the axle both to tilt vertically, the wheels accommodating themselves to any inequalities of the road, and also turning in a horizontal path, to such an extent as may be required for the purpose of steering the engine. The steering gear is generally worked from the footplate by a worm and wheel at the end of a transverse horizontal shaft, around which are coiled double chains—one winding and the other unwinding as the shaft revolves. The front axle is thus drawn into, and held in whatever, position is required for turning the engine, or for travelling straight forward.

The water and coal are carried at the rear of the engine, the top plate of the water-tank forming a foot-plate for the driver and steersman, coal being carried behind the driver, where stowage is provided for about an ordinary day's supply; but the water-tank

usually requires replenishing several times in the course of a day's work. For this purpose the engine should be fitted with a "water lifter," a little instrument on the principle of the Giffard injector fixed in the tank and fed with steam from the boiler. By means of an india-rubber suction-hose the tank may thus be filled in a few moments with water drawn from any convenient brook or pond.

The engine must be fitted with reversing gear, so that it may be driven in either direction. The flywheel should also be arranged so that a strap may be conveniently led from it to drive any machine or line of shafting. A set of governors should also be provided for service when thus employed, though they are very seldom used while travelling upon the road. An additional tank may be placed underneath the barrel of the boiler if required; and the lid of a tool-box, fixed alongside the boiler, forms a convenient platform for the attendant when cleaning or examining the engine.

A sufficient amount of weight on the driving wheels is required to absorb the full tractive power of the engine, but excessive weight upon the front wheels increases the friction of the steering gear, and causes the front wheels to "burrow" amongst loose material on the road. It is therefore advisable to put the bulk of the weight upon the hind wheels (which may be made wide enough to carry it), leaving sufficient weight only upon the front wheels to enable them to control its direction.

With respect to single-cylinder traction-engines, the following particulars are the result of many years' experience. Each nominal horse-power requires approximately 10 circular inches of piston-area. The actual horse-power is about four times the nominal; piston speed, 350 to 400 feet per minute; working pressure, 130 lbs. on the square inch; heating surface, 17·5 square feet, and grate-area, 0·75 square foot per nominal HP.; coal-consumption, 4 to 4·5 lbs. per indicated HP., with a consumption of water of about 28 lbs. per indicated HP., equal to an evaporation of say 7 lbs. per lb. of coal. These are not very economical results, but it must be borne in mind that simplicity of construction is considered of more value than the economy obtainable from feed-water heaters, a high grade of expansion, or any elaborate arrangements tending to complicate the mechanism of the engine.

The net useful load which can be drawn by any traction-engine depends greatly on the nature of the road. With ordinary wheels, on smooth pavement or on slippery or "greasy" roads, the engine may have much difficulty in propelling itself alone up an incline, while on good dry and sharp macadamized roads it might possibly haul a

gross load of three times its own weight up the same gradient. On a level road the resistance due to a thick coating of newly-laid road-metal may be equivalent to an incline of 1 in 10 on a good hard road.

The following Table shows approximately the gross and net effect which can be obtained from these engines on macadamized roads in fair condition:—

Nominal Horse-Power.	Weight of Engine (empty) in Tons.	Weight of Engine in Working Order (Tons).	Steam-Pressure in lbs. per Square Inch.	Indicated Horse-Power at 400 Feet Piston Speed.	Number of Wagons in Train.	Weight of Empty Wagons in Tons.	Net Load, (contents of Wagons) suitable for Level Roads.	Gross Load, (Engine, Wagons, and Contents) on Level.	Net Load on Incline of 1 in 10.	Net Load on Incline of 1 in 10. (Extra Good Roads.)
						Tons.	Tons.	Tons.	Tons.	Tons.
6	9	10	130	25	2	5½	12	27½	9	10
8	10½	12	130	35	2	5½	16	33½	12	14
12	13	15	130	55	3	8¼	21	44¼	18	21

The data in the above Table are for single-cylinder engines, cutting off at about ¾ stroke.

As the weight which can be hauled by a traction-engine depends on the adhesion of the driving wheels upon the roads, numerous attempts have been made to produce a wheel with sufficient elasticity in the rim to present (when compressed by the weight of the engine) an enlarged bearing surface upon the road. A number of such wheels are described in Mr. Head's Paper, the whole of which are now practically obsolete.

The wheel illustrated in Fig. 5 has been recently brought out by Messrs. J. and H. McLaren, and Mr. I. W. Boulton. It is being manufactured by Messrs. John Fowler and Co., Messrs. Aveling and Porter, and Messrs. J. and H. McLaren. It has a broad cast-iron rim, *a*, with cells or slots, *b*, about 6 inches square cast all round its circumference. These cells are 6 or 8 inches deep, closed at the bottom, but opened towards the outside of the periphery of the wheel. A hard-wood block, *c*, cut lengthwise of the grain, is fitted loosely into each cell, one end projecting a little beyond the rim of the wheel, and the other bearing upon an elastic pad or buffer, *d*, between it and the bottom of the cell. A suitable provision is made to prevent the blocks from dropping out as the wheels revolve. When the engine is in motion the weight upon the rim of the wheel

compresses the blocks so that those in the lowest and adjoining cells come in contact with the road at the same time, forming a large and continuous flat tread to the wheel, and so increasing its adhesion on the road. On paved streets the use of these wheels is specially advantageous, for not only is the tractive power of the engine enormously increased, but possible damage to the paving setts, caused by the chipping action of ordinary wheels is entirely avoided. A considerable number of engines furnished with these wheels have been at work in the Manchester district for some years, and the results have been so satisfactory that certain local authorities, who, by virtue of special powers had practically prohibited the use of traction-engines within their districts, have waived their restrictions in favour of engines mounted upon these wheels. As an instance of the advantage resulting from the use of these wheels, it may be stated that recently, an 8-horse engine fitted with them moved a boiler weighing 30 tons, on a trolly of 9 tons weight, from Dukinfield to Oldham without any difficulty.

Experience has shown that an enormous amount of wear and tear is occasioned by the shocks sustained by the engines in travelling over rough and uneven roads without springs. The wood-block wheels just described serve as an excellent spring, effectually breaking the shocks, and increasing the durability of the engine. Nevertheless, a great deal of attention has been directed to the question of mounting traction-engines upon springs, and several ingenious and fairly successful plans have been brought into use. The great obstacle consists in the presence of the steel spur driving gear, which makes it difficult to allow any movement of the axle, without throwing the teeth of the various wheels and pinions out of pitch.

The use of spring wheels forms one fairly successful solution of this difficulty, and about one hundred engines fitted with them are at work, giving satisfactory results. The driving-wheels are constructed of double rings of iron tee-bar with steel cross-plates riveted on with countersunk rivets. The boss or nave of the wheel has wrought-iron ribs to which the spokes are bolted. These spokes are made of the best spring-steel plates about 9 inches wide by $\frac{1}{2}$ or $\frac{5}{8}$-inch thick. Each plate is bent to a pear-shape, with the narrow portion fastened to the nave, and the crown resting upon the rim of the wheel where the plate is divided, the two ends being held in their places by a clip fastened through the rim with two strong bolts. When the weight of the engine comes upon this wheel, the lower spokes are compressed, and those at the top are

elongated a little. In order to avoid putting twisting-strain upon these spring spokes, the driving force is not communicated to the rim through them, but is transmitted through a strong driving arm fixed to the differential gearing wheel, and coupled by a link to the rim of the driving-wheel. The front end of the engine is carried on a pair of Timmis's helical springs, a slot-hole in the bed-castings allowing the centre pin to move up and down as the working of the springs may require.

The following arrangement of spring gear for driving-wheels, introduced by the Author's firm, is perhaps more mechanical than that of spring spokes. The engine in this case is mounted on laminated springs, J J (Fig. 6), of the same pattern as is usually employed in locomotives. Each spring, which is suspended under the axles through vertical links and a cross-head, takes a bearing, K K, upon the axle-boxes, L L, which are free to slide up and down in the guides, M M. These guides are fixed to the side plate of the fire-box, N N, which is carried backwards for the purpose, as already described. The axle-box, L L, consists of a bushed casting having two slippers, O O, trunnioned into it, and turned in a circular form to slide vertically in the guides, M M, which are bored out hollow for the purpose. In the event of one wheel mounting an obstacle and causing the spring to act more on one side than on the other, the slippers still maintain their vertical position, while the bearing is free to accommodate itself to the angle taken by the axle. In order to admit of the axle thus moving vertically without the teeth of the spur gearing being thrown out of pitch, the main spur driving-wheel P is not fixed on the axle, but is carried in a strong cast-steel bracket, Q, fastened to the side-plate, N, of the fire-box. This is in the form of a clasp, bushed with brass, grasping a large trunnion, P^1, cast on the back of the main steel spur driving-wheel, which is thus maintained in pitch with the main driving-pinion. On the face of each driving-wheel are two strong crank-pins, R R. Wrought-iron links, R^1 R^1 (Fig. 7), are coupled at one end to these pins respectively, and at the other end to the main driving-boss, S, which carries the toothed pinions, T T, of the differential gear. It is evident, however, that if these links, R^1 R^1, were coupled directly and rigidly to the driving-boss, S, when the two points of connection were in a horizontal position, the springs on the main axle would become inoperative, the one link being in tension and the other in compression. The main driving-boss, S, is therefore driven through the two intermediate cross-shaped bell-cranks, U U. These bell-

cranks work on pins, V V, which fix them to the main driving-boss, S. The links, R^1 R^1, take hold of each of them respectively by the outer end, through the pins, V^1 V^1, and the two legs of each bell-crank rest on the pins, W W. These pins pass through the rim of the main driving-boss, S, and are screwed into washer-plates, X X, which bear on coil-springs Z Z. These plates and springs serve the double purpose of breaking the shock occasioned by suddenly starting the engine, and permit the carrying springs to act in any position of the driving-wheels.

This arrangement has been found in practice to answer admirably. Three engines so fitted were sent to France to run a light parcels service between Grenoble and Lyons, a distance of nearly 70 miles. The journey had to be accomplished by night, between the hours of 7.30 P.M. and 7 A.M., or at an average speed, including stoppages, of rather over 6 miles per hour. About two and a-half hours were spent in stoppages at various towns to take up and set down packages, so that the average speed maintained was nearly 8 miles per hour. The roads in many places were very bad, being crossed at intervals by numerous open drains or water channels into which the engines dropped with great violence. Nevertheless the service was accomplished with great regularity, and without a single accident in the working of the springs. Engines of similar design are now employed in New Zealand, Brazil, &c., on rough roads without giving the slightest trouble.

Messrs. John Fowler & Co., Leeds, who were amongst the earliest makers of traction-engines, have adopted a system of volute suspended springs acting directly upon the axle. The axle-boxes are free to slide vertically in horn-blocks, and the pitch of the gearing is kept true by coupling-links between the shafts, which are thus allowed to vary their relative positions as may be required by the action of the springs, without altering the distance apart of their respective axles. This system is illustrated in Fig. 8, where the second-motion shaft A runs in fixed bearings. When the springs are in action, the intermediate, or third-motion shaft B, moves round the second-motion shaft as a centre, being held in position by the radius-links C C. Through this shaft the power of the engine is transmitted to the main gear by the wheel and pinion D D. This, again, is held in its proper position in relation to the main axle by a second pair of coupling-links E E, so that a sufficient range is given to the springs without interfering with the proper pitch of the spur driving-gear.

Messrs. Charles Burrell and Sons have also introduced an in-

genious device for the same purpose, which is illustrated in Fig. 9. In this arrangement the crank-shaft runs in fixed bearings, and communicates motion to the countershaft B by means of a pinion gearing into the spur-wheel C. This wheel revolves upon a fixed steel stud in the form of a tube D, to which the countershaft B is connected by a universal joint E. The other end of the countershaft is carried in a bearing F, free to move up and down in the horn-block G bolted to the side plates of the fire-box, which are carried backwards for the purpose. The bearing, or axle-box F, is coupled by a link H to the axle-box J of the main axle, which is free to move vertically in suitable guides S, fixed to the horn-plates, so that both axle-boxes rise and fall together with the movement due to the action of the springs L. The power is communicated from the counter-shaft B by a pinion *m*, gearing into the spur-wheel *n*, which brings the power of the engine to bear on the main axle in the ordinary way. The steel tube D, which also forms a stud for the double-speed spur driving-wheel C, is carried quite across the engine, and takes a bearing through the intermediate axle-box G upon the main horn-plate, thus forming a very solid support for the spur-wheel, as well as a substantial stay for the two horn-plates. Volute springs, like those of Messrs. Fowler and Co., are employed, being readily accessible for adjustment or repairs.

The practice of making traction-engines upon the compound principle is increasing, though by far the largest number of engines now at work have single cylinders only. Each type has its own special advantages. A single-cylinder engine is able to concentrate a larger amount of effort into a single "lift," or for a short "sprint," when required to lift itself or its load out of an awkward hole, or over a bad length of road. But where coal is expensive, or water scarce, compound engines have a decided advantage, as in favourable circumstances an economy in fuel of as much as thirty per cent. may be effected. Moreover, the shocks upon the crank-pins, gearing, and other working parts are less severe, and as the steam is expanded down nearly to atmospheric pressure, the noise of the exhaust is much reduced, and the danger of frightening horses considerably diminished.

On the other hand, compounding considerably increases the number of working parts, though the wear and tear is not necessarily increased in the same proportion, as the strains on the various parts are (with double-crank engines) to a large extent reduced. With tandem cylinders, or with both cylinders working

on one cross-head, the strains, instead of being reduced, may really be intensified, and one advantage of compounding is thus altogether lost.

The best ratio of cylinder-capacity has been found in practice to be about 2·4 to 1. The steam-chests should always be to the outside, so as to be easy of access for examination or adjustment, and a handy "pop" valve is usually provided, so that the driver can turn a sufficient supply of high-pressure steam into the low-pressure cylinder to start the engine in the event of the cranks standing in a position in which the engine will not start in the usual way.

The following examples show the work actually done by several sizes of traction-engines:—

Hauling Marine Boilers.—This duty is efficiently performed by an engine of 12 nominal HP., with two high-pressure cylinders, each 8 inches diameter by 12 inches stroke. It is working regularly in the streets and on the docks at Liverpool, hauling all sorts of heavy traffic, but is especially adapted for moving large marine boilers from the different engineering works to the ships lying in the docks. In one case the total load, exclusive of the weight of the engine, was 80 tons; viz., a boiler weighing 60 tons, on a trolly weighing 20 tons. To move this weight, at least sixty horses and thirty men would have been required, seriously interrupting the traffic for hours; whereas in this case, three men with the traction-engine delivered it under the crane on the quay, a distance of nearly 2 miles, in about fifty-five minutes.

Crane-Engine. — A traction-engine, with a single cylinder, 10 inches diameter, 12 inches stroke, with ordinary rigid wheels, and a 7-ton crane in front, is in regular use in one of the large marine engineering establishments in Gateshead, where it is used as a portable travelling-crane, as well as for hauling marine boilers and heavy castings to the 60-ton crane on Newcastle quay. In this case the principal difficulty consists in braking these heavy loads down a steep incline, which in places is as much as 1 in 10; and the loads to be dealt with occasionally reach 52 tons, including the wagon, but apart from the weight of the engine.

General Heavy Haulage.—In the Sheffield district, a number of men who call themselves "contractors" have each acquired from three to half-a-dozen traction-engines, and either let them out on hire by the day, or themselves undertake the moving of heavy

loads. In this way large quantities of flour, coal, and other materials are daily sent to the outlying villages in the Peak district, which has hitherto been without any railway communication. One contractor is largely employed at iron- and steel-works, moving heavy articles such as armour-plates, hammer-blocks, and other weights occasionally exceeding 50 tons. He is also employed in hauling, by road, boilers, spur-wheels, stern-posts, and other bulky articles which cannot be conveniently carried by rail. These are frequently taken long distances, such as to Newcastle, Liverpool, &c., without any trouble. Another contractor in the Peak district traverses a distance of 32 miles daily, with an 8-HP. engine. The trip consists of a 16 miles journey to the railway-station with the empty wagons, returning the same distance with a load of 13 tons of coal. The weight of the two wagons is 5½ tons, making a gross load of 18½ tons, exclusive of the weight of the engine. This performance has been maintained for several years, making an average of 192 miles per week. In summer weather, with good roads, the outward journey has been frequently made with a load of about 12 tons of limestone for road repairs. This involved a detour of several miles, which brought the average distance travelled up to 205 miles per week.

In the granite district of Leicestershire, at a large quarry where formerly both horses and a traction-engine were used, the comparative cost of transport was found to be no less than £492 in favour of the engine in a single year. Consequently steam-power has been since exclusively adopted.

Such instances could be multiplied indefinitely, but sufficient has been said to prove the enormous benefit of steam for road-haulage, compared with animal power.

Thousands of steam traction-engines are used for agricultural purposes, but the work in which they are employed presents no features of special difficulty.

With respect to the cost of working traction-engines on common roads, the following figures, based upon actual experience, may be taken as a fair average, when working under normal conditions. The data refer to an 8-HP. engine, one of a number owned by a contractor near Doncaster. This engine is principally used for hauling bricks and tiles from their place of manufacture into the country, an average distance of 17 miles. The cost of the engine, ready for the road, was £560; and the price of four wagons, mounted on springs and fitted with draw-bars, screw-brakes, &c., complete, was £332, or a total capital expenditure of £892, say £900.

	£	s.	d.	£	s.	d.
Interest on £900 for twelve months at 5 per cent. per annum				45	0	0
Depreciation and renewal of capital at 15 per cent. per annum				135	0	0
One driver fifty-two weeks at 30*s.* per week	78	0	0			
One steersman fifty-two weeks at £1	52	0	0			
One assistant ,, ,, 18*s.*	46	16	0			
				176	16	0
Oil, waste, stores, &c., three hundred days at 2*s.* 6*d.* . .				37	10	0
Coal, three hundred working days at 10 cwt., 150 tons at 15*s.*				112	10	0
Making the total working expenses per annum . .				506	16	0

Taking a useful load of only 12 tons each trip, the total weight handled in three hundred working days would amount to 3,600 tons carried a distance of 17 miles, or 61,200 ton-miles, which, divided into £506 16*s.*, would give a rate of 1·98*d.*, or a trifle under 2*d.* per ton per mile, or a saving of at least 75 per cent., compared with the cost of doing the same work by horses. This economy would naturally be much increased if the engine could be loaded both ways.

In view of this great saving in the cost of carriage, the limited use of steam on common roads may at first sight appear surprising. It is, however, easily accounted for by the number of restrictions already referred to under which the engines are worked, and the prejudice which exists against them, especially in rural districts.

The fact that so many engines are engaged in doing the heaviest class of road-haulage, in all parts of the country, with a wonderful immunity from accident, would appear to indicate that the time has come when these irksome restrictions might be wholly removed, while on the other hand, more stringent regulations might be imposed, for the protection of the general public, without detriment to the real development of this important means of transport. Amongst other things, a compulsory inspection of boilers is urgently called for, as it is well known to makers of traction-engines that many boilers are working in public places, at pressures for which they are not at all suitable, and are consequently a constant source of public danger. Some test of fitness should also be exacted from those who are put in charge of such engines. Many are entirely ignorant of the responsibility which attaches to them, and the risk which is daily incurred through their incapacity or carelessness.

The Paper is accompanied by 6 Photographs and by 7 tracings, from which Plate 1 has been engraved.

[DISCUSSION.

Discussion.

Sir John Coode. Sir JOHN COODE, President, said that Mr. McLaren's Paper contained a very complete and exhaustive record of the advance which had been made in the manufacture of traction-engines during the last seventeen years. He had described in great detail the various improvements introduced, and he was sure that the members would authorize him to convey to the Author their best thanks for his Paper.

Professor McCracken. Professor McCRACKEN said he purposed only to refer to a few of the causes which gave rise to what had been spoken of as "rural prejudice." He could say nothing from an engineering point of view; but, as a land-agent responsible for the roads and general amenity of a considerable tract of country, he thought that the rural objection to unrestricted steam traffic on the roads was of a more substantial nature than mere prejudice. It was to be feared that the traction-engine was regarded by most country people, as it was considered at common law, in the light of a nuisance, but no doubt a necessary nuisance. The general dislike to steam-traffic on the roads arose from three causes: first, the danger of setting fire to thatched buildings, ricks, or dried herbage by the waysides; secondly, the damage done to the roads; and thirdly, the danger to life and property from the scaring of horses.

The first danger was due chiefly to negligence on the part of the drivers, and was one which might readily be overcome; but at present it gave rise to occasional trouble. The second objection, the damage done to the roads, was a very serious one. In districts where traction-engines were numerous, it meant a substantial addition to the road-rates. It was all very well to say that the roads ought to be made to bear the traffic upon them, and no doubt the main roads under the management of the County Councils were able to do so in most cases; but when they came to the by-roads, which were in the hands of the townships, neither the thickness of the macadam, nor the culverts, nor the bridges, although they might be amply sufficient for all the local traffic, had been calculated to carry anything like such weights—exceeding forty tons—as had been mentioned in the Paper. If the owners of traction-engines were prepared to come forward and offer to bear a fair proportion of the cost of maintaining the roads, then this objection might be overcome; but as long as it fell

Professor McCracken. entirely upon the ratepayers, they would grumble at having their roads cut up. He suggested, that instead of £10, £20 or £25 should be paid for a licence, the money so obtained being handed over to those responsible for the roads to be expended in making them fit for heavy traffic. This payment, whatever the amount fixed, should be sufficient to relieve the owners of engines from the responsibility of making good damage to bridges, &c., and might be regarded by them as an insurance premium. Engines fitted with springs or wooden blocks might well be granted licences at a cheaper rate, as the injury done by them, especially to bridges, must be much less than by engines with perfectly rigid wheels. The use of wagon wheels at least one-fourth broader than those commonly met with might, he thought, be fairly insisted upon. Turning to the third objection to road engines, namely, their effect on spirited horses, that was no matter of prejudice, but a source of serious inconvenience, and frequently of grave danger. However thoroughly horses might become accustomed to trains, it was a most difficult matter to get them reconciled to traction-engines. Their usual course on meeting the engine in a narrow lane was first to shy, then with a plunge and bolt to dash betwixt Scylla and Charybdis—between the wagon on one side and the ditch or fence on the other. In nine cases out of ten, the passage was safely accomplished; but in the odd case, the result was a wreck. The culpable negligence of the drivers in charge of engines was too frequently the cause of much of the trouble. He agreed with Mr. McLaren's suggestion, that more care should be exercised in the choice of drivers. Owners often employed cheap men in order to save a few shillings a week, without troubling themselves much about their fitness for the work. He thought that if drivers were required to possess licences, granted only after the most rigorous inquiry as to their qualifications, the public would feel much safer, and the present dislike to traction-engines would gradually disappear. The fear of being suspended for a time, or of losing his licence altogether, would act as a most salutary check upon the conduct of the driver, and keep him much better up to his duty. The law requiring that a flagman should proceed twenty yards in advance of the engine might have an air of antiquity about it, but he feared that it would be long before it could be dispensed with. It was particularly necessary on narrow roads with sharp curves, or steep inclines, or where the intervention of trees shut out the view ahead.

The regular inspection of engines by a Government official was

another suggestion which deserved the utmost support. He thought it was an exceedingly favourable symptom for the development of the use of steam on common roads, that so many suggestions had been made and remedies proposed by a practical engineer, and he had no doubt that when the present difficulties were overcome there would be a still greater development in the use of traction-engines to the advantage of the makers and the users, and also of those who lived in the rural districts. Any new safeguards should, however, be fairly tested before the old restrictions were finally cancelled. Professor McCracken.

Mr. HENRY MCLAREN said that the adoption of Professor McCracken's proposal would have the effect of selling up all traction-engine men. He wished to point out that the system suggested would involve an expenditure of £20 a year for each county through which it was necessary to pass, and that in case of an engine working in Staffordshire, a licence would have to be taken out for Cheshire, Derbyshire and Yorkshire, in order that the engine might travel to Leeds to be repaired. As they had often to wait three months for a licence it became a very slow and expensive job, and the engine therefore had to go by rail. The Author had stated that butt-joints were never used in traction-engine boilers. Messrs. Aveling and Porter, of Rochester, however, used double butt-straps outside and in, and he believed that it was an advantage. It was strange that in repairing locomotives they found longitudinal grooving in the barrel plates, especially if they were lap-jointed; but he had never seen longitudinal grooving in traction-engine boilers which were lap-jointed. He thought that the buckling action, due to the boiler-shells not being properly cylindrical, did not occur with lap-joints of traction-engine boilers, which were usually small in diameter, and the plates heavy in proportion to the steam-pressure carried. They found plenty of pitting or grooving round the foundation-rings and flange-plates, especially where they were held by longitudinal stays, the boiler not being, as it were, allowed to breathe. He had particularly looked for longitudinal grooving in traction-engine boilers, some of them thirty years old, and had never yet seen it; perhaps some of the members of the Institution would tell him why it should occur in a locomotive boiler. The Author had stated that the engines ran with two speeds. Within the last ten years two speeds had been adopted, and he found three speeds advantageous in countries where engines were not limited to 4 miles per hour. It would be a very great advantage if the law would allow engines mounted on springs and with smooth wheels to run say 6 or 8 miles per hour. Mr. McLaren.

Mr. McLaren. He could not help saying, though he made hundreds of ordinary traction-wheels, that they were barbarous things, and cut up the roads considerably, but they were an absolute necessity in consequence of the limitations as to speed. It was necessary to have a heavy load, and in order to move it they must get sufficient adhesion. The engines referred to as working in France ran with smooth wheels at a speed of 8 miles an hour or more, and they pulled 12 tons very comfortably without the slightest signs of slipping. In this country they had loads, including wagons, of 21 or 23 tons, and therefore had to use the big cog-wheels which pulled the roads to pieces as well as pulling the load. If the legislature would allow higher speeds, lighter engines might be run, having smooth wheels, and taking half the present load, and it would be a great saving to the roads as well as to the culverts and bridges. Another point of importance was that of the winding-drum. He had recently returned from Australia and New Zealand, where traction-engines were largely used, and had found the winding-drum indispensable in crossing rivers where there were no bridges. The spring arrangement shown in Fig. 5 was the outcome of their French experience. They had tried all classes of spiral springs. As long as they could run 3 or 4 miles an hour spiral springs could be used; but at a speed of 8 or 10 miles the jolting was so excessive that they sometimes broke a complete set all round in a day. After three or four months' experience in France they gave up the spring wheels and spiral springs altogether. They then devised another arrangement which was shown in Fig. 5. The spring was in a stirrup, and the engine rested on the top of the spring; the stirrup being hung from the crosshead K. They first tried fastening the springs to brackets underneath the tender and firebox of the engine; but this caused leakage. They then adopted this self-contained spring arrangement. The main idea was to enable the springs to be easily changed, because changing springs at two o'clock in the morning on the Alps, 2,000 feet high, was not a desirable occupation. By taking off the nuts, which were on the top of hanging-bolts so that they could be easily got at from the foot-plate, the whole spring arrangement would drop down so that the axle-box rested in the end of the guides, and then the spring could be taken out and changed. But such was the irony of fate, that, from that day to the present, they had never broken another spring. He remembered a Frenchman holding up a spiral spring, and saying, "How can you expect a little bit of steel like that to carry an engine? You must fatigue the metal. Put in big laminated springs, such as are used on ordinary wagons, and

then you will have no more trouble." Recently, in New Zealand, he had made several trips with a compound traction-engine fitted with springs as shown in Fig. 5, Plate 1, one trip being on the West Coast road, which crosses the mountains from Christchurch to the West Coast. This engine was used for hauling the wool from the squatters' stations in the Grassmere district over this road to Christchurch, a distance of 75 miles. The load was from ninety to one hundred bales, carried on three wagons, and the engine owner received 9*s.* per bale delivered in Christchurch. They did the round journey (150 miles), including loading, in from two and a half to five days. The engine-driver and steersman were the only men in charge of the train, but they got assistance from the station hands for loading. The engine required from 10 to 15 cwt. of New Zealand (Westport) coal per day, both the speed and the consumption of coal depending very much on the state of the roads and rivers. On the trip he made, they crossed eleven rivers and streams, every one of which had to be forded, there being no bridges. The road was very narrow, and the gradients as much as 1 in 8 in some places, and they had miles of road all under 1 in 11. The highest point was the summit of Porter's Pass—3,090 feet above sea-level. In crossing the rivers when they were in flood, the fire was frequently drowned out, and he noticed that the driver always took care to have a full head of steam before starting to cross, so that if he lost his fire, he still had sufficient steam in the boiler to carry him through. As a rule he left the wagons with his steel rope attached to them, and when the engine was got safely across, the wagons were hauled over by means of the winding-drum. All the river-beds were loose shingle and boulders, and the currents were very rapid. It was rough treatment for the steel fire-box; but he was informed that they had done that sort of thing for years, and the fire-boxes stood it without apparent injury. They had to substitute wrought-iron grate bars, in place of the original cast-iron bars, as the latter were liable to drop in halves after having a cold bath. He thought watertight ash-pans and damper-lids would be an advantage. The engine in question was fitted with three speeds, viz., 2 miles, 4 miles, and 8 miles per hour, with a piston speed of 500 feet per minute. The working pressure was 160 lbs. per square inch. He found the three speeds of great advantage in this class of work, as the engine could be kept working at its maximum power, the speeds being changed to suit the various inclines. There was very little running with the regulator partly shut, the driver changing into a quicker speed instead of

Mr. McLaren.

Mr. McLaren. closing the regulator, or notching up with the reversing handle. One notch up appeared to be the favourite position for the reversing handle. This engine was one of several of similar design owned by his brother, W. A. McLaren, of Christchurch, and all his engines were certainly kept in first class running order; but they were worked without mercy, this one having run over 2,700 miles upon this and similar roads with gross loads of 20 tons, during the previous six months, without a breakage or failure of any description. He considered that this freedom from breakage, and the speed at which they were able to perform this difficult work, was due to the good system of springs shown in Fig. 5, the three speeds, good cast-steel, and last, though not least, good men on the engines. He had laid on the table some photographs showing the old and the new method of wool-carting in New Zealand. In the old arrangement, ten bullocks hauled a wagon loaded with nine bales of wool, taking many days to perform the journey; on the other hand, the traction-engine was photographed with a load of ninety-nine bales of wool (as she arrived at Christchurch), having done the round journey of 150 miles in 2½ days, including the time spent in loading.

Mr. Cowper. Mr. E. A. Cowper thought the Institution was indebted to the Author for collecting and bringing before the members the numerous facts relating to traction-engines. He wished that he could say steam-carriages, by which he meant carriages travelling at a fair and reasonable speed for passengers. He well remembered some fifty-one or fifty-two years ago, when he was nearly out of his time, Walter Hancock's five steam-omnibuses travelling along the New Road from Paddington to Finsbury, and carrying passengers as a regular every-day affair. He fondly thought that after the trials made by Cugnot, in France, in 1769; Goldsworthy Gurney and Captain Trevithick, 1802; Murdock, 1784; Col. Macaroni, Ogle, Church, Burstall and Hill, and others, they had, at last, in Hancock's steam-carriages, got steam fairly launched on common roads. But since then steam had been treated almost as badly as in the time of Cugnot; for, although the engine and its maker had not been thrown into prison, the steam-carriage was not allowed to go beyond a walk, and must have a man with a flag walking in front to show what an evil thing was behind him. It was to be hoped that some of the irksome restrictions would be removed, and the more perfect the steam-carriages could be made the sooner the public would demand their use. Many minds had been at work to improve the machine, the boiler, which for a long time was the

one vexed point, having now settled very much into the locomotive type, and for a traction-engine, which must have weight in order to do its work, this was a satisfactory form, but for quick-running steam-carriages was rather inconveniently heavy. Nothing better, however, had been brought out. Hancock's boiler occasionally gave trouble by one of its plates giving out. It was composed of a number of thin plates, bossed or dished up, and put in pairs face to face with buckstaves and tie-rods, the fire passing up between each pair of plates in a thin sheet, the water being in a thin sheet between the plates. He was glad that the Author had turned his attention to spring-wheels for traction-engines, and hoped he would make a good one for steam-carriages to run at a moderate speed. He might mention that cushions for the spokes to press on were introduced by Mr. James Taylor, in 1858, in his "steam elephants"—a name which he (Mr. Cowper) had given to the engines—and they allowed the wheels to give to some extent and imitate walking, thus greatly reducing shocks. The effect of a very slight spring might be seen in bicycles with india-rubber tires and wire spokes, which he had suggested in 1868. For those same engines he had suggested the application of "White's dynamometer" arrangement of wheels, so that both driving-wheels could pull with the same power, though at different speeds, as in going round a corner. That arrangement had now been copied into tricycles and other vehicles. The mode in which the power should be applied to the driving-wheels, so that the cylinders, pistons, and guides, should not feel the shocks caused to the wheels when passing over irregularities, had exercised many minds; and Hancock, he believed, was the first to solve the problem, as he drove with a chain from a wheel on his crank-shaft, nearly on a level with the wheel on the driving-axle, and thus the play of the springs did not affect the rotation of the wheel, whilst the engine was on springs. Even George Stephenson was troubled about that, and had to alter the angle of his cylinders. He was glad to see that the Author had an arrangement for driving a wheel moving with the spring, from a wheel on the engine itself, by the introduction of springs and two links; but if he would put two links to one wheel and a light frame of four rods to those links, and two other links from the frame to the other wheel, he would have a complete "Clement's driver," and be able to do away with two strong levers and four springs. Mr. Cowper.

Sir FREDERICK BRAMWELL observed that he had spoken at so great a length seventeen years ago on Mr. Head's paper, read before the Sir Frederick Bramwell.

Sir Frederick Bramwell.

Institution, that he had very little to say, unless he repeated the observations he then made. Mr. Head's paper embraced the whole subject of steam on common roads. Mr. McLaren's had been practically confined to one branch of it—that of the traction-engine—upon which, as he had said, he did not know that he had many observations to make. One statement in the Paper was, however, new to him—namely, that Houldsworth was not, as he had thought, the first to propose, in 1826, the use of that combination of bevelled wheels, which was now employed for compensating motion. Such wheels were, it appeared, to be found four years previously in White's book. He had always thought that Houldsworth was the inventor, and he had so said in the discussion on Mr. Head's Paper. With respect to the necessity of there being liberty of relative motion between the two driving-wheels of a carriage on the road in order that it might with ease make turns, that was recognized from the outset; in fact, it was almost obvious, and it would be found that Trevithick in 1802, in his description of his common-road locomotive, made a provision of that kind, which in his case was the simple one of using a clutch for each driving-wheel, the steersman throwing out either wheel as required, in order to drive by the other one only, leaving the wheel that had been thrown out loose on the axle. Trevithick went on to say, "It is also to be noticed that we do occasionally, in certain cases, make the external periphery of the wheels uneven by projecting heads or nails, or cross-grooves or fittings to railroads when required, and that in the case of a hard pull, we cause a lever-bolt or claw to project through the rim of one or both of the said wheels, so as to take hold of the ground." He also pointed out with regard to affording to the wheels relative liberty that the clutch which drove the wheel was, in each case, one wherein the driving was done by a pin in the driver bearing against another pin in the driven, and that this construction, leaving so large a portion of the circumference of the circle unfilled, was adopted in order that the wheels might accommodate themselves to the respective lengths of the inside and outside curves to an extent equal to about three-fourths of the circumference of the wheel. That is to say, the outer wheel could over-run the inner one for a length equal to about three-fourths of its circumference before it took up its driver on the other side. That was a contrivance that Hancock also adopted in the engine which Mr. Cowper had mentioned, and that he (Sir Frederick Bramwell) had also on previous occasions fully described before the Institution. One of the

Sir Frederick Bramwell.

objections to the use of traction-engines, to which reference had been made, was their liability to set property on fire. That certainly was a matter that could easily be prevented. So far as he knew, there were only two modes by which locomotives on railways set property on fire. One was the escape of the fire up the funnel; and the other was, if the ash-pan were not properly made, the emission from it of lighted pieces of fuel which, coming in contact with the spokes of the wheels, probably of the tender, were sent along as a ball was sent by a cricket-bat. There was no fear of this second mode of scattering fire happening where, as in the case of a traction engine, the speed was restricted to 4 miles an hour. With regard to emissions of fuel from the funnel, that could be easily prevented, without any injury to the working of the engine, if the builders would merely put a grating in the smoke-box just above the tube-level, as this was a position where the area of the box was so great compared with the area really needed, that it was possible to put such a grating across without any appreciable injury to the draught. If that were done, this head of objection to the passage of a traction-engine would be removed. But there still remained the serious difficulty of frightening the horses. It was a lamentable thing that it should be so, but so it was. He could not help thinking that persons acted very unwisely and very unfairly towards their horses. They put a horse into a stable, which was constructed by an architect whose notion apparently of providing accommodation for a horse was to practically imprison him in the dark, whatever light there was commonly came through a half-open door, the horse's back being towards the door, and his eyes towards a dead wall. The horse was kept under these conditions for some twenty hours out of the twenty-four, and then it was regarded as a matter of surprise that the horse, being suddenly brought out into the glare and bustle and clatter of the street, was frightened. He did not suggest that the fronts of our houses should be given up for stables in order that horses might have a full view of a main thoroughfare; but he did suggest that wherever there was a chance of doing it, a horse, when in the stable, should (as was the case in many loose boxes) be able to look out of the window and see the daylight and the things that were passing by. Then again, as regards this question of frightening horses, no effort in the traction-engines was made to conceal the machinery. Mr. Hancock's carriages, which were for passenger traffic, had entirely concealed machinery, and were provided with ordinary coach or omnibus bodies, and he could state, from his

Sir Frederick Bramwell. own repeated experience in the use of these carriages, that the horses in the omnibuses, regularly working along the same line of road, paid no attention to the steam carriages after the first fortnight's run. He knew that the machinery could be concealed effectually, but this might be done in one of two ways; it could be concealed effectually, and so as to diminish the annoyance of the horse, or it might be concealed in such a way as to add to that annoyance; he alluded to instances where the machinery was enclosed in a wrought-iron box, which acted like a big drum, resulting in the production of an alarming noise. But that was not the kind of casing he desired. He suggested that without difficulty the working machinery of a traction-engine might be boxed in, and that, by this concealment of all moving parts, the tendency to excite alarm in the horse would be diminished. With regard to the suggestion that unless compound engines were used it was difficult to reduce the pressure of the steam so as to avoid a noisy blast, he might refer once more to Hancock's carriages; these had not compound engines, but the steam was emitted into a silencing-box, which broke the blast so effectually that the engine travelled along without any noise. In the present day, traction-engines on tram-roads were fitted with air-condensers (Hancock in his latest engine had such a condenser), and these went along without any such noise of blast as attended a locomotive engine. He could not help thinking that there was a good deal to be said on both sides with regard to the question of steam on common roads. On the one hand, traction-engines were very useful; on the other hand, they undoubtedly caused alarm to horses that were not used to them. He thought it was clear that everything should be done, and that a good deal might be done to diminish the sources of that alarm. That they would ever succeed in doing it entirely he doubted, because, as it had been said, the biggest ass in creation was a horse. Some years ago he had to do with tram-cars driving by compressed air. There was no noise or sound of any kind, and the car coming towards one appeared as any ordinary tram-car would appear if running down a gentle incline by the action of gravity; but, even under these circumstances, some horses, not many, were alarmed. He was inclined to think that they would be alarmed at the sight of anything coming towards them unless they saw one of their own fraternity pulling it along. He did not know whether he had dreamed it, but perhaps Dr. Anderson would tell him if he were right (or at all events it might be ascertained by referring to the archives of the Royal Agricultural Society) in believing that Mr. Boydell,

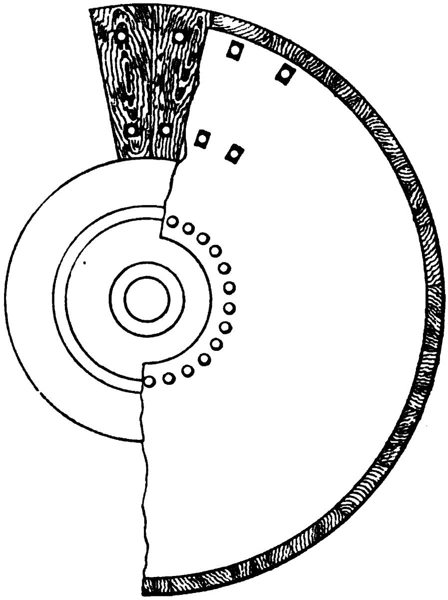
many years ago, either of his own mere motion or by reason of some Act of Parliament, did absolutely harness a horse to a steam traction-engine in order to go in front, and thus satisfy its fellows it might meet on the road that the carriage was being moved in an orthodox manner. He did not put this forward as being authentic, but it had in some way got into his mind, and (as the judge said who found something on his notes) he did not know how it could have got there unless somebody had said it. Sir Frederick Bramwell.

Mr. J. F. Churchill said that traction-engines had been largely used in years gone by, and the experience gained with regard to them was very well known. In Wales, some years ago, traction-engines were used for carrying slates from the quarries to the sea-ports, especially from the Cwmllan Quarry to Port Madoc, and from Llanberis to the Port of Carnarvon. They were also used by the surveyor on the road from Shrewsbury to Holyhead to draw the metal for the repair of the road. But in all those cases they were found so injurious, doing so much damage, breaking the culverts, cutting up the roads, and causing accidents with horses, that they had to be abandoned. He had seen traction-engines used on a large scale in the island of Ceylon, where, on the Haputale Mountains, 4,000 feet high, large quantities of rice were taken up to the estates, and coffee down, by native bullock-carts. The cost of the transport up and down was from 1*s.* to 3*s.* per ton per mile. The merchants and planters interested in the estates sent to Australia, and procured a number of large heavy cart horses and wagons, in order to get over the difficulty and cheapen the transport; but owing to the climate and the steepness of the hills they turned out to be a failure, and the plan was abandoned. They then sent an engineer to England and got out some of the best traction-engines that could be made, which they tried to work for a couple of months; but owing to the constant breakages they were found to be utterly useless. The wear and tear of the roads was no consideration to them, as they were kept in efficient order by the government; but the result was that the use of engines was abandoned, and they had eventually to resort to the bullock traffic again, and at the present time a railway was being made to the estates. He did not see how it was possible to use traction-engines on ordinary roads, because they always interfered with horse traffic, unless there was a special road made to travel on. A previous speaker had suggested that the difficulty might be overcome if the engines were allowed to travel 8 or 10 miles an hour, but no horse in the world would face such an engine passing at that rate. They were admirably adapted for Mr. Churchill.

Mr. Churchill. the removal of heavy weights such as boilers of 60 tons for short distances; but they would never answer for ordinary traffic on ordinary roads. [The President asked to what cause the wear and tear in Ceylon was attributed.] The machinery was constantly breaking, and it was found very difficult to steer round the corners, especially going down hill with heavy loads.

Mr. Richardson. Mr. JOHN RICHARDSON said he could confirm Sir Frederick Bramwell's statement with reference to the use of horses in front of traction-engines. In 1856 at the Leeds Show some winding-

Fig. 1.



engines were exhibited and took the prize for ploughing, and those engines were steered by horses, and he might remark that these horses were the only ones which were frightened. He (Mr. Richardson) had sent for exhibition a drawing of Thompson's road steam-engines, because he thought that no Paper on the subject could be considered complete that did not mention those engines, which certainly marked an epoch in the history of traction on common roads. So far from these being an obsolete form there were many such engines still used, some for quick but more for slow traffic. There was no engine which could drag heavy weights

in and out of difficult roads and yards with so much facility as the Thompson road steam-engine. At the time when there was such a rage for this engine his firm (Robey and Co.) made fifty or sixty of them within eighteen months. They had some influence with the local authorities, and, in spite of the laws to the contrary, they were permitted to run 8, 12, and even 20 miles an hour on the common roads. At first the horses belonging to the neighbourhood were frightened, but they all got used to them within a very few weeks, and would pass them without difficulty when Mr. Richardson.

Fig. 2.

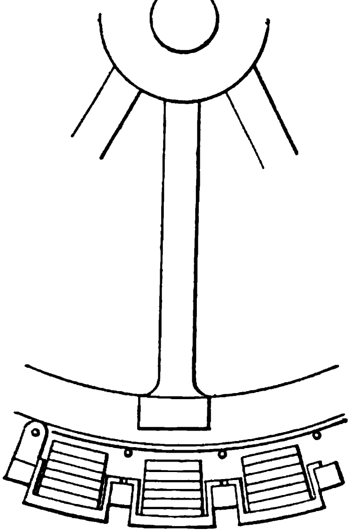
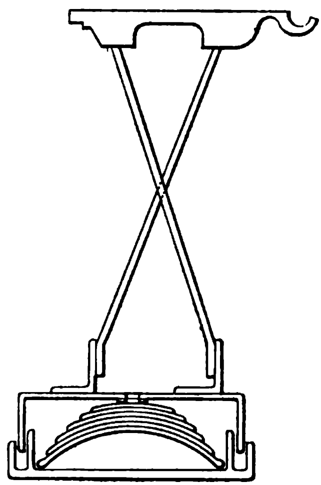


Fig. 3.



going at comparatively high speed. He had no doubt that if horses were properly trained to the sight and sound of such engines there would be no difficulty in running them at those rates. Many of them were still running; only a short time since they executed an order for one, and within the last few weeks they had given an estimate for another of those engines to a person who had been using two for nearly twenty years. The engines had many advantages, and he thought they would continue to be used in special cases, but the great cost of them militated somewhat against their extended use. He had also brought two illustrations of driving-wheels which had not been noticed in the Paper—the Thompson wheel and the wheel suggested by Mr.

Mr. Richardson. Pendred. The latter consisted of an iron boss (*Fig. 1*), and about one quarter of the quantity of india-rubber put round the boss of the same thickness as in the Thompson type. Impinging upon the india-rubber were blocks of wood endways of the grain held between two steel-plates in which they could work in radial slots, and those blocks rested upon the road, affording the same flat surface that the Thompson tire did, and giving considerable tractive power. Another form was that of Mr. Mackinder, of Lincoln, which, as at first made, was not a perfect success. It consisted of a number of steel boxes (*Fig. 2*), with flanges held by wrought-iron straps attached to the rim. Each box had a spring in it, and the dirt used to get in, so that in a few months the springs were broken. They were replaced by blocks of india-rubber (*Fig. 3*), and only within the last three months an engine so fitted was brought in for repairs after working for sixteen years, the wheels being in very good order; very little repair was needed, and the engine would be sent out again in a week or two almost as good as new. He had no doubt that the horizontal form of engine was the more convenient for driving thrashing-machines, and would be used; but for anything like passenger-traffic, or light goods traffic supplementing the railway, there was a great field for a road-steamer that could be driven at high speeds, and handled with a degree of facility which could never be obtained by the four-wheeled engine.

Mr. Stanger. Mr. W. Harry Stanger wished to say a few words from the practical engine-driver's point of view. It was his vocation, many years ago, to be a driver of traction-engines, and in that capacity he had considerable experience both of the ordinary type of engine, and of the Thompson road-steamer; he had also had charge of a road-steamer in Brazil for two years, and was therefore able to speak upon some points which had not been thoroughly discussed. With regard to horses, they were not troubled with them in Brazil, as they met but few. In England, however, his experience was, that horses were frightened at first, but it largely depended upon the person driving them how much they were frightened. If a farmer was in the habit of using traction-engines, his horses would go past them without trouble. It was otherwise, however, with those who did not like the engines—especially road surveyors. He remembered distinctly seeing a road surveyor in his gig dancing about for half an hour, simply because he would not allow his horse to pass an engine standing on the roadside without steam or fire in it. The advantages of the Thompson road-steamer, as compared with the ordinary engine, were chiefly in regard to the

greater handiness of the former. Any one who had tried to get an ordinary engine out of a dirty occupation-road through a narrow gate into a field, would understand the difficulty of just hitting the right place between the gate posts; but with a road-steamer, the driver would be able to steer his engine straight through the gateway without the slightest trouble. Mr. Stanger.

The lighter weight upon the steering-wheel, and the shorter distance between it and the drivers, together with the better arrangement of the steering-gear, made the road-steamer much handier than the ordinary type of engine. Doubtless there had been improvements in the steering-gear of traction-engines since his time, but the two leading-wheels were still retained, and as long as this was so, he failed to see how an engine so fitted could be as facile in steering as one with a single leading-wheel. The working parts of the road-steamer were always boxed in, whether in the horizontal or vertical type, and it thus fulfilled one of the desiderata mentioned by Sir Frederick Bramwell without any sacrifice of accessibility. The road-steamer with vertical engines at the back of the boiler was a better arrangement than that of the horizontal pattern, as in the former case the fireman was on the same footplate as the driver, who could keep a watchful eye upon his subordinate. The arrangement by which either driving-wheel could be thrown out of gear by means of a clutch, was very handy when dealing with light loads, for a driver who knew what he was about, could run his engine well up to a corner, switch the inside wheel out of gear, get round, and have the wheel in gear again before there was any tendency to slip. With heavy loads this was a more difficult operation. He admitted that for heavy agricultural work in England, the road-steamer could not be recommended in face of the great improvements made in the ordinary type of traction-engine as described in the Paper; but for light loads, he contended that it possessed advantages over it. The water-carrying capacity was nearly double; there was a larger percentage of the total weight upon the driving-wheels where it was wanted; the single guiding-wheel was very lightly loaded, thus rendering the operation of steering prompt and easy. The great point against the road steamer was the enormous expense of the india-rubber tires. They certainly were not wanted on the steering-wheel. The cost of a full set of tires ranged from £200 to £300, according to size. They were splendid things for pulling, but the cost and labour of keeping the necessary armour-plating in order was very great. It was no joke in a tropical climate, where he generally worked at night for the sake

Mr. Stanger. of coolness, to have to sit up the next day repairing this armour-plating. The road-steamer could, however, be easily fitted with such a spring-wheel as that described by the Author, or by Mr. Richardson. So fitted, he believed, that weight for weight, power for power, and coal for coal, the Thompson road-steamer, properly driven, would do the whole of the work that the Author had spoken of as being done on the French line, quite as efficiently, at 25 per cent. higher speed, and without more for repairs. He would be glad to know if the estimate given at the end of the Paper of the yearly cost of working an 8-HP. traction-engine were based upon actual results. He observed that the engine was said to work three hundred days in the year. If so it was a marvellous testimony to the excellency of the design and workmanship. He certainly never knew of a traction-engine that equalled it. With regard to the statement that traction-engines had been a failure in Ceylon, as a driver of that type in different parts of England, and of another type in tropical places far worse than Ceylon, he imagined that the fault was not in the engine, but more probably in the people who managed it. It seemed extraordinary that any one who went to the expense of buying a powerful traction-engine should not have sent out a competent driver, in order that such a fiasco might have been avoided.

Mr. Carey. Mr. ARTHUR CAREY said that Mr. Cowper and Sir Frederick Bramwell had partly anticipated what he was about to say. He would speak only as a user of traction-engines and road-locomotives for a period of twenty years, not being able to say anything from the manufacturer's point of view. The Author, after enumerating the conditions to be fulfilled by a practical road-engine, had spoken of the frivolous restrictions imposed by the legislature, and had then referred to the advances made during the last seventeen years. From Mr. Carey's experience, the advances made had not been as rapid as the "frivolous restrictions," and it would be a great advantage if Mr. McLaren's Paper, showing how desirable it was that such restrictions should not be put in the way of road-locomotives, were brought before the local authorities. He might be permitted to refer to the report of the Select Committee of the House of Lords in 1871. In that Committee Lord Vernon asked Sir Frederick Bramwell a question as to the speed of the engines, and he then referred to what Mr. Cowper had stated, the running of Hancock's engine from Paddington to the Bank thirty-five years ago (at present fifty-four years ago). Sir Frederick Bramwell said that the speed attained

was eight or ten miles an hour. Asked by Lord Vernon as to the horses being frightened, he replied that after a short period all the omnibus horses passed the engines as they would pass any other vehicle on the road. Then asked by Earl Radnor as to noises, &c., his reply was that there was no noise from steam and no smoke. It was evident, therefore, that no rapid progress had been made, because when he (Mr. Carey) left off in 1881, he had been hunted down by chairmen of the benches of magistrates, local surveyors and others, for showing a little smoke (although he generally used smokeless coal), and also for making a noise, and on account of the red flag mentioned by the Author. Lord Vernon further asked Sir Frederick Bramwell whether there was any risk to the public, and the evidence which he gave in reply was as applicable at the present day as it was at that time. He said that undoubtedly there was; and Mr. Carey quite agreed with that remark. With his experience of two or three dozen engines, he admitted that there was a risk, but it was chiefly on the part of those who met the engines, and did not know how to work their horses. Sir Frederick Bramwell had stated that on that very morning, or the day before, under his window, a horse had taken fright at a Guards' band going by. No doubt horses did take fright at drums and bands and other noises besides those of road-locomotives. Reference had been made to the licences which had to be taken out. That was since his time, and it was evidently a difficult thing to deal with, especially with regard to the portable engines. He could mention a case during the last week in which a 30-HP. Ruston and Proctor's engine had to leave the French Exhibition to go to Battersea for some trials, and then on to St. Pancras afterwards, and twelve horses were sent for it by the Midland Railway Company, under the idea that it was going to St. Pancras. The engine was got out all prepared to leave, and the night was wasted because the men would not take it to Battersea as they thought it had to go to St. Pancras, and another day was wasted in getting a contractor to bring other horses. If the engine had been self-propelling and there had been no absurd restrictions, it could have been got through London to Battersea in a quarter of the time, and with much less risk and trouble. The Author had mentioned the water-space round the fire-box, which varied in width from $2\frac{1}{4}$ inches at the bottom to 3 or 4 inches at the top. Mr. Carey's experience of water-lifts, and other means of replenishing the tender on the road, was that they got such dreadfully bad water in some places, such as ponds by the roadside, that it would Mr Carey.

Mr. Carey. be a great advantage if the makers could increase the water-space, if only by ½ inch. From some photographs he had placed on the table, members would see the damage done to the roads by the narrow-wheeled wagons used. There could be no doubt that if the contractors who bought those engines used wagons with wider wheels, they would do no damage except in the case of roads that were in bad order. He might refer to an engine in 1870 that took a load of 25 tons 4 miles in an hour and a half. Before the Committee of 1871, the late Mr. Tawke, chairman of a bench of magistrates, gave evidence, as well as a surveyor in his district, about the damage done by the engines. He could only say that, after a few years, the same gentleman employed his engines right and left for hauling and other purposes, and the surveyor took good care to metal the roads whenever he knew that a traction-engine was coming along. One of the photographs represented guns and mortars being drawn at Shoeburyness. It was on a frosty morning, and they started at a fast speed. Mr. Henry McLaren had said that during the last ten years two speeds had been introduced for most engines, but he (Mr. Carey) was referring to twenty-five years ago, when they had a pair of engines, both of which could run either at 10 miles or 4 miles an hour. The one that was running 10 miles an hour across the marshes one day suddenly sank into a hole. He maintained that if there had been an arrangement for passing quickly from fast to slow speed, the engine would have been out within two minutes. As it was, they had to carry the pinion on the tender or on the tool-box, or something of the kind, and it took a long time for the man to carry it round and fit it. The next day the officers told him that they had laid a trap for him, by digging a hole, putting in a faggot, and covering it with earth. The way they got out was by throwing a log down and putting on spuds, trusting to the engine to jump up, which it did. Those engines were working in 1885. He took them to the Stettin Agricultural Show, and from thence to Cologne, and ran trials against 20-HP. engines made by Schwarzkopf, of Berlin, built on the locomotive principle, direct-acting, with no cog-wheels. He need not hesitate to mention that his engines took the prize. They took 25 tons, namely, six boilers on two wagons, 1000 metres (⅝ of a mile) in eight minutes and four seconds, being stopped once at a railway-crossing while a train was passing. Schwarzkopf started by putting a jack behind his engine to give it a good start, and then, at a terrific pace, completed the journey in seven and a half minutes. The same engine that afternoon ran with one of Aveling's across the cavalry exercise

ground by the side of the carriage of the late Emperor Frederick, who was then Prince of Prussia, and must have gone at the rate of 10 miles an hour. When he first went to Essex, there were not many railways there, and he had to keep several horses; but he taught them to face the traction-engines, and a great many other gentlemen did the same. It was stated by the late Mr. James Tabor, the chairman of the bench of magistrates, that the road from Rochford to Southend was never better than after the traction-engine had been running five or six years. Of course, differential gear was a great boon. They had to remove a pin from one side of Aveling's engine to take it round a corner; in Fowler's engine they ought to have undone the brake on one side in going round the corner, which, of course, they very seldom did. The result was, that if the breakage of an axle did not take place then, it did soon afterwards, when they were running on a straight bit of road, and they could not understand how it was. Mr. Binney could tell them that the road from Barking to Rainham, twenty years ago, was not fit for people to drive on, but after the late Mr. Circuit, who bought engines from him, ran his market-garden produce nightly on the road, it was as good as any other in Essex. Mr. Carey.

Mr. C. H. Binney said as a user of traction-engines for the past sixteen years, almost entirely in Essex, he could corroborate Mr. Carey's statements as to the state of the roads on which Mr. Circuit had used his engines. He could also speak from his own experience of very heavy traction work in Essex. Wherever the roads were kept in anything like fair working order, the engines did no damage whatever, but where, owing to the negligence of the surveyors, or other reasons, they were allowed to get into disrepair, the engines certainly did make some mark, and the wagons perhaps more, though even then they did not do as much damage as the narrow-wheeled carts going along day after day in the same ruts with their ordinary loads. There was one point that militated very much against the use of traction-engines, with heavy loads especially—more, perhaps, in Essex than in many counties—namely, the "extraordinary traffic." For some years he had battled hard with that question, but, being unaided, he was obliged to give it up. He found that, after traversing a road a few times, he was met on the next market day by the surveyor of the district, who told him that he was doing "extraordinary damage" to the roads, and that he should be glad to know what proposition he was prepared to make as to the repair of them. A good deal of opposition was also experienced, not so much Mr. Binney.

Mr. Binney. from the farmers as from the gentry of the neighbourhood who drove carriage-horses kept in the stables alluded to by Sir Frederick Bramwell, with their backs to the light, and brought out once in twenty-four hours full of life and expected to face all the difficulties referred to with unmoved spirits. The coachmen also raised much greater opposition than there was any necessity for. His own experience had been that the majority of horses would face the engines without the slightest annoyance after a very short period. He had driven many horses over a very large area of the country, and he used to select his horses without regard to their temper, but he had only found two that he could not get to pass a traction-engine quietly within a week or so. The bridges in their districts were a very great difficulty. The practice of the surveyors was to put up a notice on certain bridges to the effect that the owners of traction-engines were liable for any damage done; but he had been many times over those bridges after the notice was put up, and used them year after year without the slightest damage. While the County Councils and other authorities raised unnecessary obstacles he did not think that the traction work on common roads would be carried on to any great extent. He had not had much experience with regard to springs, but the little he had acquired had not led him to put them on his own engine. He preferred the wooden block with an india-rubber or other buffer under it, and believed it to be more durable and better fitted for ordinary agricultural roads, where they had to get in and out of stackyards, gateways, and pass all sorts of obstacles. The necessity for taking out licences for each of several adjoining counties was a serious drawback which affected them materially in Essex. In his own case he had frequently been asked to go into two or three different counties in a very short space of time. Those difficulties, together with others that he had mentioned, had led him to give up traction-hauling altogether. He never could get anything like the number of days that Mr. McLaren had mentioned out of his engines after allowing for ordinary breakages and delays. The major portion of the work was done during the summer months or in the early spring or autumn, as in the winter the roads were so soft that the traction wheels, even under the best conditions, would make more marks than the local authorities were pleased to see.

Mr. Elwes. Mr. R. G. Elwes said that no reference had been made to one point of some interest to those who were connected with traction-engines, namely the experience that had been gained in North Italy as to the frightening of horses. Some years ago he spent

the winter in the north of Italy studying the steam-tramways or light railways, as they really were, laid along many of the principal roads, especially in Lombardy. On those light railways, which were only separated from the ordinary roads by lines of stones, trains of three or four carriages drawn by locomotives of the tramway type, but without any arrangement, at that time, for preventing noise or the emission of steam and smoke, were allowed to go at the rate of 12, 15, or sometimes 20 miles an hour. The experience there was that, after a very short time, the horses of the district became accustomed to the trains, and took little or no notice of them; and it appeared to him that if steam-traction was to be used to any great extent on ordinary roads horses would have to be taught to meet those engines, just as army horses were taught to stand the sound of guns. Mr. Elwes.

Mr. W. W. Beaumont said he would not presume to speak on the Paper but for the fact that some years ago he had a good deal of experience with traction-engines on farms and on roads. All who thought that steam on common roads ought to be more commonly used would feel greatly indebted to the Author, seeing that anything that would draw public attention to the existing restrictions on the use of traction-engines ought to do some good. As Mr. McLaren had said, no one who made a thoroughly good traction-engine could object to proper restrictions, but there was a great deal to be said against restrictions that were anomalous and vexatious. One or two had been mentioned in the Paper, but there were others that were much worse. It was impossible, for example, for a traction-engine to cross London at the present time without breaking existing rules in one way or another. Engines were not allowed to move at more than certain speeds, and they must cross London between certain hours; if they moved at the specified speeds they could not cross London within that number of hours, and if they did not do so the drivers were taken up and punished for being stuck somewhere on the road. Those anomalies existed in the country as much as they did in London, and if it were not that many of the prohibited things were winked at, it would be impossible to use the engines as much as they did. There was a large proportion of the agricultural work done in the present day that would not pay but for the use of traction-engines. They ought, therefore, to protest against the suggestion made by a previous speaker, that another £20 should be added to the cost of the licence. If anything were done, he would suggest that the licence fee should be taken off altogether, and that the recommenda- Mr. Beaumont.

Mr. Beaumont. tions of the Special Committee of 1873 should be accepted. He believed that almost every one of those recommendations might be made law without detriment to any interests whatever. He thought the Author would add very much to the interest of his Paper if he would give fuller information about the gearing. He had told them that most of it was made of steel, but he had said nothing as to the speeds, and the way in which the various parts wore, the pitches used, the width of the wheels, and so on, points that were of very great interest in connection with the use of gearing for such exceedingly heavy and varied work. With regard to the statement that the engines would sometimes when at work lift up in front, he had himself seen them very severely tested—for example, with a 40-ton lump of granite behind two traction-engines. In that case the load was ultimately put on boiler-plates, which were moved on and on until a part of the road was reached which was even softer than the rest. The late Mr. Thomas Aveling was present, and finding the engine-drivers were unable to move the lump of granite, he jumped on the engine and had the drag-link that was between it and the truck moved, and a heavy piece of chain put in; he then put the engine back with at least 18 inches of slack, started at full steam, and simply moved the load of granite out by running at it. Every time he started the engine it jumped up in front, but he succeeded by the excessive strength of the parts in jerking the load out of the soft spot it was in. The engine referred to had chain-gear, and it was well known that engines so fitted would haul heavier loads than those with several intermediate shafts and wheel-gear. It had been said that the gearing failed so continually in Ceylon that they were obliged to give the system up. Mr. McLaren ought to say something as to how he had got over that difficulty. The stresses brought to bear upon the engines were sometimes even greater than had been mentioned. Quite recently he had seen a McLaren traction-engine in Sheffield trying to get some very heavy loads up a hill paved with granite. Sacking was thrown under the wheels to make them grip, but this was soon cut through or moved to one side, allowing the wheels to slip round. The engine was doing, perhaps, not less than 40 HP., and running at the rate of 180 revolutions per minute for a few seconds; and the next moment the wheels were nearly dead still. They had therefore between the engine and the road-wheels the whole of that work, except that which was done after the wheels started slipping, thrown suddenly on or off those parts. He repeated that he thought that everything should be done to bring the recom-

mendations of the Committee of 1873 before those who could do something towards their adoption. Mr. Beaumont.

Mr. J. McLaren, in reply, said he thought it fortunate that the discussion had been opened by Professor McCracken, who represented the prejudices that were opposed to the working of traction-engines on the country roads of England. He had very fairly placed his views before the Institution, and they were not only entitled to considerable respect, as coming from a gentleman who had the management of large estates in Cheshire, but they contained several practical suggestions which he, as a maker and user of traction-engines should be willing to adopt. The Paper was not intended to deal, and did not deal, to any considerable extent, with the use of traction-engines for agricultural purposes; its main object was to present the position of road-engines in relation to heavy traffic; and his experience, like that of most of the speakers, was, that it was very bad policy to go down an occupation road with a traction-engine having a heavy load behind it. The County Council roads were in most cases able to stand the racket of those engines and all the loads they could reasonably draw. There could be no objection to reasonable restrictions; it was necessary that those who used the roads for horses should have the same freedom as was asked for those who used them for traction-engines; and if a contractor for his own profit employed a traction-engine upon a County Council road he would not object to pay a certain sum for the use of the road, and so relieve the rates which were paid by those who had to maintain it. Some of the speakers were evidently not aware of the fact that engines for agricultural purposes did not require any licence. A licence was a payment imposed upon the users of traction-engines used for purposes outside agriculture; and if the payment required was £10, or £20, or even more, he did not think that many contractors would object, provided they received their *quid pro quo* in the shape of protection from frivolous and vexatious persecution at the hands of local boards and magistrates' courts, so long as they conducted their business on the lines laid down by the Act of Parliament. With regard to the alleged danger from fire, it was almost unheard of. Stacks and cottages, had, indeed, been fired, but such accidents were so rare as scarcely to need consideration, especially as the danger could be so easily provided against in the way suggested by Sir Frederick Bramwell. It had been said that certain designs of traction-engine had not been dealt with in the Paper. He had started with the idea that it was not to be an historical Paper, dealing with the Hancocks, Mr. McLaren.

Mr. McLaren. the Gurneys, and all the pioneers in the use of steam on common roads, and he had accordingly confined himself to the present practice adopted by the leading makers of traction-engines. It was a very difficult subject to handle in a scientific way. The makers of traction-engines had no formula to guide them; and they never would be able to make formulas to meet every case. They had to deal with roads varying in gradient from the level up to 1 in 8, and with atmospheric changes that made the roads slippery so that the wheels would not bite, or soft, so that they would sink into the ground; consequently there was a great deal of difficulty in devising wheels and engines which would work uniformly in all states of the weather. The designs of various makers had been exhibited on the wall, and he thought he might claim for them as well as for himself, that they had been fairly successful in dealing with the question of the employment of steam on common roads. Mr. Stanger had referred to the details the Author had given of the cost of haulage on common roads. The man from whose experience the illustration was taken was the owner of several traction-engines. The result stated was given, not as the performance of one individual engine, but as the experience of a man in the habit of dealing with those matters daily; if his No. 1 engine was not on the road No. 2 was, and the work was constantly carried on; so that the cost given might be taken as fairly approximate. He was a working-man, having started as a navvy on the Settle and Carlisle Railway, and having saved a little money, he invested it in a traction-engine on the hire and purchase system; but he was now the owner of a number that were in daily work. He was seldom in bed after three in the morning. He did not drive his own engine; but he had steam ready for the men the moment they came on duty at four or half-past four A.M. The work was mainly done in the early hours of the day, when there was not so much traffic on the roads, and they could get along without being constantly interrupted by horses. As an instance of the punctuality with which the journeys were made, Mr. McLaren was talking to him one day at his place, and asked him where such an engine was; he replied, looking at his watch, "It is just about the time that it should be back," and the words were no sooner out of his mouth than the smoke of the engine was seen over the hill. As to the experience in Ceylon, referred to by Mr. Churchill, he had no doubt that it related to a period some time ago, before the engines had been improved and simplified, and when it was very handy in working a traction-engine or a steam-plough, to be somewhere near a foundry, and

perhaps to have a spring-cart available to convey broken parts to and from the repairing-shop. He was glad to say that that sort of thing was now ancient history, and not only McLaren's, or Fowler's, or Aveling and Porter's engines, but many others, were daily working with great regularity. Mr. Cowper and Mr. Beaumont had referred to the driving of the engines. The chain to which Mr. Cowper had alluded had been entirely abandoned, and would never be revived except for toy engines where the strains were not excessive. He had had no personal experience of the making of chain-engines, but he had seen a good deal of the use of them, and had known many accidents caused by them. Chains were composed of flat links and pins, and if any one of these broke while going up a steep hill with a heavy load an accident would happen. If the engine were reversed suddenly the chain was apt to fly, and then, even if it did not strike the man in the face, there was nothing to prevent the engine from rushing headlong to the foot of the hill. With regard to the driving-gear referred to by Mr. Beaumont, the improvement in the manufacture of steel as mentioned in the Paper had been the means of enabling them to overcome that difficulty. The gearing was now made of the usual cast-steel, so well known, which seldom broke, and he did not think in their experience, which embraced the manufacture of some hundreds of traction-engines, that they had ever had more than one per cent. of breakages. They had had the pinions worn; the pitch of driving pinions varied from $2\frac{1}{2}$ to $3\frac{1}{2}$ inches, and they had seen them worn till they were not more than $\frac{1}{4}$ inch or $\frac{5}{16}$ inch thick. The Hadfields, the Spencers, and other leading steel-makers seemed to have got the gearing matter right. The only other difficulty in dealing with the gearing of traction-engines was that they could not get the full width of tooth. It would be observed that in all the illustrations the wheels looked narrow in proportion to the pitch. But the law imposed certain limits of the width of the engines, and they were obliged to pay respect to those laws. Moreover, the difficulties of getting into gateways and narrow places rendered it imperative that the engine should be kept as narrow as possible, so that they had to keep the spur-wheels much narrower than the usual proportions of toothed gearing. The intermediate gear varied from $1\frac{7}{8}$ inch upwards, seldom exceeding $3\frac{1}{2}$ inches in pitch. Sir Frederick Bramwell had referred to the clutches, but that, he thought, was also ancient history, and it would not be necessary to revert to it again. The differential gear which had been described, effectually superseded them. Mr. McLaren.

Mr. McLaren. There was a difficulty with respect to the covering in of the engine. In discussing and considering the traction-engine question they should not forget that there was a limit of price, and although it was not a very expensive matter to cover in the working parts of a traction-engine it was seldom done. To some extent that might be due to expense, but it was mainly due to the objection of the drivers, it being difficult to get to the engine for cleaning and taking off the glands and working parts for adjustment and repair. That difficulty did not arise in the use of tram-engines, where there was not the same limit of price, and where they had a regular shed-day for qualified mechanics to attend to them.

He was well acquainted with the wheels referred to by Mr. Richardson: he did not think of them when he wrote his Paper; but in no case should he have referred to them any more than to the Thompson wheel and the other matters which had been already dealt with in Mr. Head's Paper in 1873. The Thompson road-steamer, with all due respect to Mr. Richardson, had practically become obsolete. There were a few working in Glasgow and a few elsewhere. There was one working at J. H. McLaren's at Leeds every day, but these were exceptions; and as the principles of their construction were wrong, their use could never become general. The boiler would never make steam enough; and Lieutenant Crompton, or perhaps Mr. Stanger, might be able to state what their experience was in the use of boilers of that description. When he used to see them at work it was a case of stopping every 400 yards to put the jet on, to get a little more steam. They also required a separate independent framing, and all that cost money, and added to the weight, besides closing up the working parts and making them practically inaccessible. He believed that the great bulk of the road-steamers were made with horizontal cylinders. Then they were three-wheeled engines; the front wheel ran in a castor, and there had been a great deal of trouble in keeping the castor right. There was no differential gear on them as a rule. Clutches had been adopted, and much bad language had sometimes been used when the inner wheel had been thrown out of gear and the outer wheel had been surging round and trying to bury itself in the soft ground. With all respect to Mr. Stanger, he would rather take his chance with an ordinary modern traction-engine in a country lane with a threshing-machine behind it, than with any Thompson's road-steamer ever constructed. The question of extraordinary traffic was a very serious and anomalous one. Magistrates and judges told them that the traffic carted by

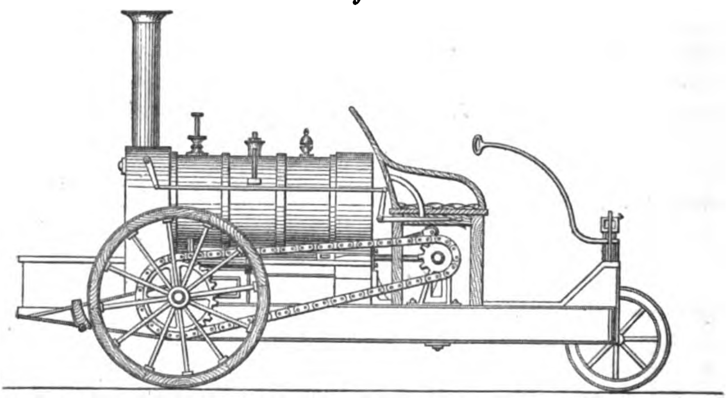
horses was ordinary traffic. A stone-quarry might be opened out, and if the stones were drawn by horses, it would be considered as ordinary traffic; but if by a traction-engine, it had been held to be extraordinary traffic; and under the clauses of the Locomotives Act a difficulty arose at once, which led to expensive and tedious litigation, and interposed serious obstacles to the use of traction-engines. On the question of driving he could not too strongly express his opinion that some qualification should be required from men who were allowed to take a traction-engine into a street. They ought not to be chosen merely because they would work for 13*s.* or 15*s.* a week, but for their capacity and knowledge of the engine; and the legislature would do wisely in exacting certain qualifications from them, and in requiring a certain inspection of the boilers. The makers of the engines often saw wonderful things coming in for repairs, the wonder being that they had not blown up long before they arrived at the works. If they could ensure a fair consideration by the legislature of the whole subject of the use of steam on common roads, and have the bye-laws which were frivolous and vexatious eliminated and new ones of a practical character substituted, it would open the way for a very great development of steam-traffic to the advantage of everybody concerned. Mr. McLaren.

Correspondence.

Mr. John Hayes said, that having regard to the great improvements in the manufacture of carriages and vehicles of all kinds, and also in the condition of country roads, the question might fairly be raised, whether "steam on common roads," had not now a much wider scope than its application solely to traction-engines for the haulage of heavy loads. The use of electricity during the last few years for traction purposes, as exemplified in "the electric tramcar," and "the electric omnibus," should do much to remove the prejudice attached to the idea of having conveyances propelled on ordinary roads by mechanical power, and should prove a powerful factor in modifying legislation as applied to this subject generally. An ordinary traction-engine travelling on a common road was a fruitful source of danger to the public, owing to its huge size and unsightly appearance, as well as the noise of the steam issuing from the chimney being apt to frighten young and restive horses, and for this reason stringent regulations were necessary. He was of opinion, however, that it was now quite feasible to construct, at a moderate cost, a light Mr. Hayes.

Mr. Hayes. steam-carriage capable of carrying say four or five passengers with their luggage, to run with perfect safety to the ordinary traffic at from eight to ten miles per hour along country roads, the speed being reduced when nearing or passing through towns and crowded streets, to say four or five miles. In order to do this, high-pressure steam should be generated in a boiler preferably of the locomotive type; the engines should be placed underneath and should run at a high rate of piston-speed, and be connected to the driving-wheels (which need not be of large diameter) by mean of pitch-chains, or other suitable gearing. The experience gained in the manufacture of pitch-chains in connection with tricycles and other well-known mechanical applications, had enabled them to be made with a degree of accuracy and reliability previously unattainable,

Fig. 4.



and in a similar manner the use of steam-tramcars in towns had stimulated engineers to minimize, if not to overcome, the noise and difficulty of the exhaust steam in the chimney. He was, therefore, of opinion that the time had arrived when a fair amount of success might be expected to attend any serious attempt to place before the public a light steam-carriage for use on ordinary macadamized roads. It might be interesting to mention that in March, 1859, a description appeared in 'The Engineer,' of a steam-carriage belonging to the Marquis of Stafford, and of a journey made by Lord Stafford and a party of noblemen from Buckingham to Wolverton on the same, along the country roads in Buckinghamshire. Mr. Hayes had a vivid recollection of having as a boy seen this same steam-carriage at his late father's works where it was taken for alterations, his father at that early date having given

much attention to the subject of steam power on common roads. Mr. Hayes.
Fig. 4 was a representation of this little engine.

Mr. EDGAR WORTHINGTON said that the steam road-engine was Mr. Worthington.
perhaps nearer akin to the portable engine than to the locomotive. But although the working conditions on a common road and a railway differed so widely, a comparison of the proportions of road-engines given by the Author, with those of passenger railway-locomotives might not be without interest. First, the piston-speed was only half that of an express passenger-locomotive. Secondly, the heating-surface per actual horse-power was double, and the grate-area five times greater than that required by an express locomotive. Thus the boiler was very large in comparison, and formed in addition, as pointed out by the Author, both body and frame of the engine. Indeed, were it not for the spring arrangements the rest of the machine would be very simple. In modern road-engines there appeared to be two arrangements of spring-gear, one at the axle-box and the other in the driving-wheel itself. Of the three axle-box spring arrangements shown in Plate 1, Figs. 6–9, that designed by the Author, while ingeniously providing for all possible movements of the driving-wheels, consisted of a large number of parts. And, seeing that springs were also required to take the jar of the heavy wheel itself, greater simplicity would be obtained by returning to the plan of having a rigid axle-box, and putting the whole of the spring-gear in the rim or spokes of the wheel. For rapid country traffic over bad roads, this might not suffice; but on the good main roads around industrial centres, the advantages of greater simplicity might be thus obtained.

A formidable list of restrictions under which road-engines worked had been compiled by the Author, but it might be noted that they had also their privileges. These engines were now permitted in many of our crowded streets to throw off large quantities of visible exhaust-steam, which tram-engines were compelled to reduce, if not abolish, by means of expensive surface-condensers or otherwise. The extended use of road-engines in towns would probably rouse public opinion to further restrictions, and the additional encumbrance of condensers might be demanded. But here the introduction of compounding might serve to reduce the steam nuisance, as well as to increase the power of the engine. The comparatively large boiler, and the advisability of having a soft and noiseless blast also favoured the application of the compound system. The 30 per cent. fuel economy mentioned by the Author might be difficult to obtain by compounding with the low boiler-

Mr. Worthington. pressures at present in vogue. But, if a low-pressure cylinder were added to any of the single-cylinder engines, working continuously with a steam cut-off at three-quarters of the stroke (see Table on p. 9), the maximum power of each machine would be increased about 30 per cent., without any additional expenditure in fuel; and at the same time the almost intolerable noise made by a high-pressure simple engine with such a late cut-off would be avoided. Another objection to the use of road-locomotives in populous districts was the tremulous motion which they give to the surrounding buildings. An engine, which had made daily trips through eight miles of populous streets in South Lancashire during the last ten years, with a train of three to four lorries laden with cotton goods, had from time to time proved injurious to house furniture from this cause. The use of some effective kind of spring-wheel would increase the life of the working parts of such an engine, as well as tend to remove much of the disfavour with which road-locomotives were often regarded.

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18 November, 1890.

SIR JOHN COODE, K.C.M.G., President,
in the Chair.

The discussion on Mr. McLaren's Paper on "Steam on Common Roads" occupied the whole evening.

25 November, 1890.

SIR JOHN COODE, K.C.M.G., President,
in the Chair.

(*Paper No. 2468.*)

"On the Vibratory Movements of Locomotives, and on Timing Trains and Testing Railway-Tracks."

By JOHN MILNE, F.R.S., Imperial University of Japan, Tokyo; and JOHN McDONALD, Locomotive Department, Tokyo.

THIS Paper contains an account of certain instruments which have been designed to register the oscillations and vibrations of trains, to give an automatic record of the run, and information as to the nature of the track passed over.

The first experiments in Japan were made by Mr. McDonald, who investigated the vibrations of a locomotive by observing the movements of a liquid in a bottle. This led to the devising of a number of instruments of various forms, commencing with short-period pendulums and modified forms of seismographs, and ending with the apparatus described in this Paper.

Permission to make the necessary experiments was kindly given by Mr. F. H. Trevithick, M. Inst. C.E., the Locomotive Superintendent of the Northern Division of the Imperial Japanese Railways.

Ordinary earthquake instruments were found to be too sensitive, their working being interfered with partly by the suddenness of the jolts to which they were subjected, and partly because they are affected by changes in inclination. After a few experiments it was clear that, especially for horizontal movements, apparatus with considerable stability was required, and that it must be compact and portable. The form adopted, although involving the same principle as many seismographs, is not suitable for recording earthquakes. It is novel as applied to the vibrations of rolling stock; and is at the same time so different in its construction from any earthquake machine, that the Authors consider it suggestive of new arrangements which might be introduced into seismometry.

Vertical Motion.

The vertical movements are recorded by the apparatus shown in Plate 2, Figs. 1 and 2. A is a clock-spring, kept coiled on its axle by the lever B C, carrying the weight W. When W is depressed and then set free, it returns to its normal position, but when it is raised it tends to continue its upward motion. In order to counteract this, a small spring D may be attached to the lever E, which is so adjusted as to bring the weight back to its normal position. The spring is wound by turning the drum G G, to which one end is attached, the other end being secured to the fixed axle B B. The result of this combination is that, for up and down movements of B B, some point in W remains at rest. A pointer, *p d*, is attached to the spring-drum G G, at right-angles to the lever B C; and as the instrument moves up and down, this pointer moves to the left and right, giving an enlarged or diminished representation of the vertical movements, according to the distance of the pointer *p d* and the weight W from the centre B.

Horizontal Motion.

Horizontal vibrations are recorded by means of pointers attached to two pendulums, each of which is only free to move in one plane, the two planes of motion being at right-angles to each other. The simplest form of either pendulum is shown in Figs. 3 and 4, where A is a metallic cylinder, free to swing on pivots *c c* on its upper edge. For a quick displacement of *c c* to the right or left in Fig. 3, or at right angles to the paper in Fig. 4, some line, *i i* in A, may be regarded as the instantaneous axis of rotation relative to *c c*, which is the axis of percussion.

In Fig. 3, while *c* is moved to the right or left, a point *i* in the instantaneous axis may be considered as being practically at rest; and therefore a multiplied representation of the motion of *c* is given at the upper end of the pointer *c d*, which, by means of the pin *p* (Fig. 4) sliding in guides, writes the movements of the pointer *d* on the surface S. The motions of A are made approximately dead-beat by giving a certain frictional resistance to the movements of the pointers *d*. This may be done by loading the writing needle *p*. Another method of controlling the free swing of the pendulum, adopted in the instruments constructed, is to connect the pendulum A, by a sliding joint, with a second pendulum B, as shown in Fig. 5.

For convenience of illustration, the two pendulums are here

represented as two flat bars, A and B, one pivoted at *c* and the other at *d*. They are connected by the fork *f*, attached to B, which can slide on the pin *e* projecting from A.

If the frame carrying the two pendulums is displaced to the right or to the left—say to the left, as shown by the dotted lines—inasmuch as the lower pendulum tends to fall towards the right in the direction of the arrow *g*, and the upper pendulum tends to fall towards the left in the direction of the arrow *h*, it is clear that these two pendulums may be so proportioned or suspended that the point *e* may, relative to *d* or *c*, be a centre of oscillation, and therefore the point *e* may remain practically at rest.

A more elaborate way of constructing the instrument, and one which will avoid the necessity of calculations as to the position of the instantaneous axis, is shown in Fig. 6. Here the weight A is pivoted on its axis *i i*, in the frame B, which in turn is pivoted at *c c*, in the fixed frame C; *c d* is the multiplying pointer. In this case *i i* is the instantaneous axis, which practically remains at rest while the frame C moves backwards and forwards.

It will be observed that these forms of the instrument all write with their pointers placed vertically, but by tilting the apparatus they might be made to write in any plane, even if they are placed horizontally.

Fig. 7, Plate 2, shows the instruments for vertical and for two horizontal motions at right-angles to each other, mounted in position, ready to give diagrams on a moving surface. A is an ordinary clock driving the drum B, on which the movements of the three pointers *c*, *d*, *e*, are recorded. The roller B may be covered with metallic or with ordinary paper, or may be a smoked surface, the pointers being strips of metal, pencils or pens. The apparatus H is on the principle shown in Fig. 5; but the pendulums, instead of being flat bars, are cylinders. It is represented on a larger scale in Fig. 8. The apparatus for recording longitudinal motion, I, Fig. 7, is similar to H, but so placed that the axes of its cylinders are at right angles to those of H; the pointer *e* being caused to write in the same plane as *d* by the intervention of a bell-crank lever, *k*, shown underneath. In Fig. 7, *c*, *d*, and *e* are strips of brass, writing on the cylinder B, which is covered with metallic paper. Experience has, however, proved that a brass pointer, after several hours' wear, either ceases to write, or makes only a faint mark, and for this reason metallic paper and brass pointers have now been abandoned for ordinary paper and black-lead pencils.

To obtain a continuous record, a long band of paper, rolled on a

cylinder as in the Gray-Milne seismograph, is pulled over a drum corresponding to B, Fig. 7, and wound up on another which is driven by its own system of clockwork.

The following types of instruments have been constructed:—

1. For timing trains, and giving general information respecting the condition of a line. This consists of the double-clock arrangement just described, driving a continuous band of paper about $2\frac{1}{4}$ inches broad, at the rate of 1 foot per hour. On this band only the vertical motion is written; but inasmuch as lateral jerks have usually a vertical component, these also are in part recorded.

2. For giving detailed information respecting a line. In this instrument clocks similar to those of No. 1 are employed, but the band of paper driven by them is broader, and all the components of the motion are recorded upon it. In addition to timing a train, and showing irregularities on a line, this instrument indicates curves and gradients, shows when brakes are applied, &c.

3. For testing locomotives and carriages. This only differs from No. 2 in the clockwork, which is arranged to drive the paper at the rate of about 1 inch per second for a short interval of time.

Measurement of Diagrams.

The diagrams exhibited only profess to give the absolute motion of a locomotive within short ranges.

For vertical motions up to 25 millimetres (1 inch) the diagram may be directly measured, in order to determine the vertical motion of the engine. Longitudinal and transverse motions can only be read as absolute measures up to a range of about 6 millimetres, or $\frac{1}{4}$ inch. After that they may be calculated with the assistance of the following Table, in which the measurements are in millimetres:—

——	Recorded on Diagram.	Actual motion.
Longitudinal motion . . .	5 mms.	5 mms.
	12 ,,	25 ,,
	15 ,,	35 ,,
Transverse motion	5 mms.	5 mms.
	10 ,,	20 ,,
	15 ,,	30 ,,

These figures are the result of the following experiment. The instrument was placed on a small table that could be easily shaken in any direction. The record of this shaking, as given by the apparatus, was compared with a second record made by a pointer, fixed to the table itself, and writing on a sheet of paper placed on a neighbouring table which was at rest. So long as the range of motion was not more than 6 or 7 millimetres ($\frac{1}{4}$ inch), the vibration registered by the instrument was practically equal to that of the table. For motions greater than this, it was always less than that shown upon the fixed table; the relation between the two measurements being approximately that given in the above Table. For most purposes, however, it is not necessary to determine the absolute amplitude of the oscillations.

Locomotives and Carriages which have been Tested.

The only vehicles of which the Authors have details and drawings are certain locomotives in Japan. Diagrams have, however, been taken on many locomotives whilst crossing the United States, and also in Pullman cars. In England diagrams have been taken in carriages running on the London and North-Western, the Caledonian, the Great Northern, the South-Eastern, the Metropolitan railways, &c. The longest that has been obtained as yet, shows the motion of a carriage between New York and San Francisco, a distance of about 3,300 miles.[1] Between New York and Chicago the diagram was taken in a Pullman car on the Pennsylvania Central. From Chicago to Omaha the journey was made on the Burlington and Quincy Railroad, and from Omaha to the shores of the Pacific, on the Central Pacific line.

A brief description of fifty-eight locomotives now in Japan, is given in the Appendix, and Fig. 12, Plate 2, is an outline drawing of one of those from which diagrams have been taken. As the indications of the vibration-recorder are in great measure connected with the balancing of the engines, the weights of reciprocating parts and balance-weights are given in detail, together with the equivalent balance-weight, which was determined experimentally as follows: a pair of wheels, with their balance-weights and crank-pins, were placed on level rails; a large round steel ring was then hung on the crank-pin, and from this weights were suspended until a balance was obtained

[1] The original of this diagram was exhibited.

and the wheels would rest in any position. This weight hung on the crank-pin is what is here called the equivalent balance-weight. In some engines it will be seen that the sum of these weights on one side of an engine is much less than the sum of the weights of the reciprocating parts, while in other engines these two quantities are nearly equal. It will be shown that when these quantities are nearly equal—that is to say, when only the horizontal component of the energy due to the movement of the reciprocating parts is balanced—the diagrams for longitudinal motion are small.

Table I, Appendix, gives the relation between the balance weights and the equivalent balance.

The Tokyo-Yokohama Line.

Most of the diagrams were taken on locomotives running on the line between Tokyo and Yokohama, a distance of 17¾ miles.

The following is a brief description of the track, commencing at the Shinbashi station in Tokyo. There are two lines of rails, and the gauge is 3 feet 6 inches.

Shinbashi to Shinagawa (3¼ miles; time, eight minutes).—The line runs round the edge of the bay on an embankment, on either side of which, up to this year, the tide rose. At the present time, however, the greater portion of the water-area on the land side has been filled up. The ground beneath this embankment, being the mud of the bay, is probably very soft. There are nine bridges or culverts (Nos. 1, 2, 3, 4, 5, 6, 7, 8, and 9), the largest girders having a 44-foot span. No. 9 bridge is overhead. There are three small curves, from 40 to 44 chains radius. With the exception of slight rises to the bridges, this section of the line is practically flat.

Shinagawa to Omori (2¾ miles; time, nine minutes).—On passing out of Shinagawa station, there is a cutting and a rise of $\frac{1}{300}$. Shortly after this there is a rise of $\frac{1}{100}$, and thence a gentle descent of $\frac{1}{300}$ down to the Omori station. There are three small curves of 180, 40, and 40 chains radius, and three small bridges, Nos. 10, 11, and 12. No. 10 is a 30-foot span; No. 11 is a 56-foot span; No. 12 is a 15-foot span.

Omori to Kawasaki (4¼ miles; time, twelve minutes).—On this section, with the exception of a rise of $\frac{1}{100}$, and a descent of $\frac{1}{168}$ to the Kawasaki bridge, the line is practically level. There are three small curves—one of 40 chains, one of 60 chains leading to

the bridge, and one of 40 chains leading off the bridge. There are three bridges, Nos. 13, 14, and 15, the first of which consists of three 16-foot spans; the second, which is the waterway to, and continuous with, the Kawasaki bridge, of twenty-four 40-foot spans; and the third is the bridge made up of six 100-foot Warren girders, designed by Dr. William Pole, F.R.S.

Kawasaki to Tsurumi (2 miles; time, eight minutes).—This line, with the exception of slight rises at the bridges, is practically level. There is one 32-chain curve, and one bridge (No. 16), consisting of six spans of 42 feet 8 inches.

Tsurumi to Kanagawa (4 miles; time, 12 minutes).—With the exception of three small inclines of $\frac{1}{200}$, the line is practically level. Outside the station there is a 40-chain curve. About half-way there are three other 40-chain curves, continuous with each other, so as to form an S. A fourth 40-chain curve is at a cutting just entering the Kanagawa station. There are three bridges (Nos. 17, 18, and 19). No. 17 is a 48-foot span; No. 18 is 47-foot 6-inch span; and No. 19, which is over the line, consists of two 16-foot spans. From Omori station to a point about half-way between Tsurumi and Kanagawa, the line runs across the delta of the Kanagawa River.

Kanagawa to Yokohama ($1\frac{1}{2}$ mile; time, six minutes).—Here the line, which is practically level, runs for a considerable distance on made ground round the edge of the bay, there being water on both sides of the line. There are three bridges (Nos. 20, 21, and 22). No. 20 consists of two 32-foot 3-inch spans; No. 21 of three 20-foot spans, and No. 22 of two 20-foot spans. There is one 40-chain curve.

The distances given are only approximate, and the time includes stoppages. The greatest speed between stations is about 25 miles per hour.

The diagram of vertical motion (Fig. 9), taken on locomotive No. 131, running on the line from Shinbashi to Kanagawa, shows that there is a relationship between the character of the line and the recorded movements. Soft ground can be distinguished from hard ground; while the effects of bridges and culverts have been indicated. On this line, which is remarkable for its solidity, this diagram is repeated on all the locomotives, the variations in range of motion, at different points along the line, being reproduced in similar proportion.

The Diagrams.

All diagrams on the same line show the same characteristics. For example, a diagram of vertical motion taken on March 14th, on engine No. 129, a reproduction of which is shown in Fig. 10, and which may be compared with Fig. 9, shows that after leaving Shinbashi and as Shinagawa is approached, the vibrations grow larger and larger. In fact they are larger than on any other portion of the line, and notably larger than between Shinagawa and the next station. This may be explained by the fact that this portion of the track rests on the mud of Tokyo Bay, and is therefore soft and yielding. Here and there a sudden increase in the size of the diagram may be observed, as, for instance, at the third minute after starting. This particular twitch in the motion of the pointer occurs at one of the culverts, but the cause of it has not been determined. Judging from the diagram, it appears that the train did not leave Shinagawa until 1.41, whereas it ought to have left at 1.39, that is to say, two minutes were lost at this station. From Shinagawa five and a half minutes were required to climb the incline, before descending to Omori, which is marked by the largeness of the diagram. At Omori there was a stoppage of a minute and a half, whereas, had the train kept schedule time, it should have been one minute only. Between Omori and Kawasaki there are several irregularities in the diagram, indicating soft places in the track. One of these occurs at twenty-seven and a half minutes after starting, and is probably on one of the culverts; or it may have been a sleeper that required packing, such marks being often made upon the diagrams when passing a gang of workmen engaged in repairs. The most important mark, however, occurs in the second span of the 40-foot girders, forming the waterway leading up to the large bridge at Kawasaki. This occurs regularly in all the diagrams, two and a half minutes before running into Kawasaki station. The whole of the waterway has been examined by a staff of workmen who knew nothing of the diagrams, and they reported that a sleeper on the second span of the down-track, when a train passed, yielded twice as much as any of the other sleepers. Between Kawasaki and Tsurumi, with the exception of one or two soft places, there is nothing remarkable; but between Tsurumi and Kanagawa, especially at certain points, the diagram is rather larger; and at forty-six and a half minutes after starting it is nearly as large as

it is on the Kawasaki Bridge. It is evident that there is here a soft place that requires attention. By examining the indications of the instrument along this section of the line, it may be seen that abnormal movements take place at the entrance to several of the culverts. From Kanagawa to Yokohama the track appears to be firm and solid, with perhaps one exception at a point three minutes after leaving Kanagawa. Yokohama is reached in fifty-nine minutes, whereas it ought to have been reached in fifty-five minutes, so that there has been a loss of four minutes on the journey. Where two and a half minutes were lost has already been pointed out, and the remaining one minute and a half may be accounted for on a close examination of the diagram. Information respecting loss of time and stoppages may, of course, be equally well obtained from the record of transverse or longitudinal motion.

Fig. 9 is a diagram of the same track, taken on engine No. 131. It shows the same general features as the one described.

The Tokyo-Yokohama Railway is probably as solidly built as any line, but still it exhibits irregularities. On nearly all the railroads in America and England, on which the instrument has been tried, irregularities are more numerous.

The longitudinal motion is the one which most clearly shows differences in balancing. For instance, the size of diagrams taken with an engine of type A, compared with those given by one of type B, has been as 6 to 27. Again, with No. 135 and No. 129 the longitudinal motion was 5 millimetres; with No. 90 it was 7 millimetres, and with No. 94, 6 millimetres; these engines were of class 141, type A. On the same track, with a similar load, No. 137, an engine of the same class, type B, twice gave a diagram of 10 millimetres. In all instances these locomotives have been run under similar conditions respecting speed, notching, &c. A striking feature in the diagram of longitudinal motion is that it clearly indicates ascents and descents, by deviating to the right and left of a median line. This is illustrated by Fig. 13, which represents part of the American diagram.

Curves are marked in a similar manner by the portion of the instrument recording transverse motion (Fig. 13).

With the aid of this description the remaining diagrams shown in Fig. 11, *a*, *b*, *c*, *d*, *e*, *f*, *g*, will be readily understood. It must not be overlooked that, on the same line, each carriage or locomotive will produce the type of diagram peculiar to itself; the irregularities on a line showing as excrescences upon it. Further, because the motion in a Pullman is greater than in an ordinary

carriage, it must not be concluded that the latter is the better. Whether a carriage is dangerous or uncomfortable, depends upon what may be called its "jerkiness," a quantity dependent not only upon the range, but also upon the period of the motion.

On the Consumption of Coal and Oil.

The observation that certain locomotives gave a larger longitudinal diagram than others, indicating that the work was done by a series of jerks, rather than by a steady pull, suggested the idea that such engines were not exerting their power in an economical manner, and were consequently consuming more fuel than those which moved uniformly. To test this, the Authors examined several Tables showing the consumption of coal and oil on certain sections of the Imperial Japanese Railways. The results, for locomotives of similar construction (Plate 2, Fig. 12), on which diagrams have been taken, are given in Table II, Appendix.

From an examination of this Table, it appears that the engines of type A have always burnt less coal than those of type B; and when both classes of these locomotives have been doing similar work on the same line, the difference in favour of Type A has been, in one instance, as much as 4·04 lbs. of coal per mile, which means a saving of about 14 per cent. The only difference between these two classes of locomotives appears to be in their balancing. (See diagram of wheels in Fig. 12*a*.)

The engines which used the least coal per mile, although their mileage has been great, have been those in which the difference between the weight of the reciprocating parts and the equivalent balance has been small; for instance, with locomotives No. 9 and No. 11, where the difference is only 3 lbs., the average consumption of coal has been about 16 lbs. per mile. (See Table III, Appendix.) On the contrary in engines No. 102 and No. 104, where the difference is 566 lbs., the consumption of coal has been on the average about 39·4 lbs. per mile. With a difference of 353 lbs., as in engine No. 93, the consumption of coal has been on the average about 34·2 lbs. per mile, and generally the more nearly the weight of the reciprocating parts approaches that of the equivalent balance, other conditions being equal, the less fuel appears to have been consumed.

A similar result was found with regard to the quantity of oil required. It should, however, be noted that the only fair tests are

those between engines of the same class running under the same conditions, which is only the case in the instances first cited.

Wear of Tires.

It occurred to the Authors that engines yielding different diagrams might show a difference in the wear of their tires. The few engines which have been running sufficiently long to require re-tiring, belong to No. 9 class and No. 13 class.

Comparing together these two classes of engines it was found that with engines of No. 13 class, where the reciprocating parts on either side are 70 lbs. heavier than the moment of the balance weight, 1 inch of tire was destroyed in runs varying between 156,039 and 244,806 miles. This is equivalent to wearing away 1¼ inch in from 195,048 and 306,007 miles.

Engines of No. 9 class, in which the weight of the reciprocating parts on either side is 2½ lbs. lighter than the moment of the balance weight, so that these two quantities may be considered practically equal, were found to have worn away 1¼ inch of their tires in running from 271,299 to 328,927 miles, that is to say, from 22,920 to 76,251 miles farther than engines of No. 13 class.

These comparisons apparently indicate that these engines which run farther without steam, and which give a small diagram for longitudinal motion do not wear out their tires so rapidly as others. The Authors do not, however, lay particular stress upon these observations because the data on which they have founded their conclusions are extremely meagre, and also because it would seem that the class of engine where the vertical component of energy due to rotation is unbalanced, ought to be the class in which the greatest wear should be found.

Conclusions.

Amongst other things which the vibration-recorder accomplishes the following appear to be of importance:

1. All the diagrams show variations in the speed of a train, as for instance, in ascending or descending an incline, or when approaching or leaving a station. They show on what part of a journey time was gained and where it was lost.

Stoppages, whether at stations, at signals, or at other places are clearly indicated, and the duration of such stoppages is accurately

recorded. As the distances between stations are known it is an easy matter to determine average speeds. Information of this description may possibly be of value to those who have to deal with the management of traffic.

2. The instrument may also be useful to engineers whose duty it is to inspect lines. At curves the writing point for transverse motion is thrown to the right or to the left of a central line. Curves are therefore indicated by a characteristic deviation of the diagram (Fig. 13). Variations due to carelessness on the part of the plate-layers are recorded.

Ascents and descents and even slight variations in grading are clearly shown by the pointer for longitudinal motion writing to the right or to the left of the line it would describe when in its normal position (Fig. 13).

Lastly, what is perhaps of the greatest importance, faults in sleepers, irregular yieldings on bridges, soft portions of the track, and other imperfections are definitely marked. For example, it has been shown that on the Shinbashi-Yokohama Railroad the diagram for vertical motion for the first 3½ miles is always greater than it is on the rest of the track, indicating that that portion of the road-bed is more spongy than the rest (Fig. 9).

At the entrance to the Kawasaki Bridge, on the second span of the down-track, Mr. McDonald observed that the vertical pointer always made a sudden movement of twice the usual amplitude. Here the line runs on 40-foot girders. At this place it was found that when a train passed, the sleepers yielded about ½ inch, while the sleepers on the other spans only yielded ¼ inch. The Authors would draw special attention to this particular fault because it could not be seen, and on account of the easy spring-like yielding it could not be felt; it was discovered by the instrument, and its existence has been announced every time a diagram has been taken on a passing train. That there is an abnormal yielding at the entrance to several other bridges on the Shinbashi-Yokohama line, and at several places along the track, has also been indicated by this instrument. Whether spring-like yieldings, which probably exist on many bridges, are dangerous, is a matter for engineers to decide.

An engineer with one of these diagrams before him, may, if he has familiarized himself with the use of the instrument, form a fair idea as to the state of the line, and by taking fresh ones at intervals he may at once detect any changes in the permanent way.

3. The vibration-recorder is also capable of furnishing infor-

mation of value with regard to the manner in which a locomotive should be balanced.

When the moment of the balance-weights is small, relative to what would be the moment if the weights of the reciprocating parts were hung on the crank-pin, the longitudinal motions are markedly great, whereas when these moments are about equal, the longitudinal motions are small. The transverse and vertical motions are not affected to so great an extent.

Improper balancing may lead to swaying or "nosing" of a locomotive, which in turn has led to derailment. It has often been pointed out that at each revolution of a driving-wheel there is a sudden stress, described as a "blow" upon the rail, the magnitude of which varies with the nature of the balancing. It is supposed that these suddenly applied forces result in a wear of tires and rails, and cause undesirable and possibly dangerous vibrations in bridge-work.[1]

The diagrams for longitudinal and vertical motion may be used in measuring these so-called "blows." When longitudinal motion is great, it indicates that the locomotive is doing its work by a series of jerks or impulses, which in all probability mean that force is being expended in an uneconomical manner; that such is the case is further shown by the fact that locomotives with a pronounced longitudinal movement burn more coal per mile than those of which the longitudinal motion is small. The same diagrams apparently show when there is a waste of oil, or a wear of tires or rails.

Some experiments of considerable value were made with the instrument, by causing the surface on which the diagrams were taken to run at the rate of about 1 inch per second. In this case, each vibration of the locomotive was recorded separately, and from these diagrams the maximum acceleration or the suddenness with which each backward and forward motion is commenced has been calculated (*Figs. 1, 2, 3*).

If r equals the amplitude or half the range of motion in any given vibration, and T equals the time taken to perform the backward and forward motion, the jerk, suddenness of movement, or maximum acceleration per second, is measured by the quantity $\frac{4\pi^2 r}{T}$.

Such diagrams, obtained under similar circumstances from

[1] See "Shocks on Railway Bridges," by John W. Cloud, Altoona, Pa. Transactions of the American Institute of Mining Engineers, vol. ix. p. 375.

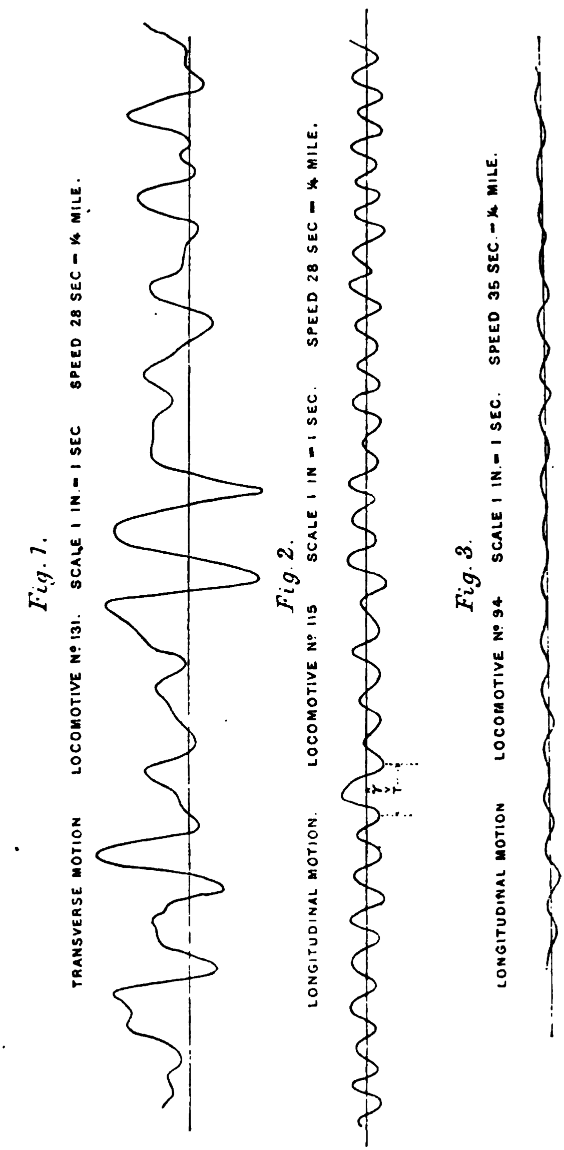


Fig. 1. TRANSVERSE MOTION LOCOMOTIVE No. 131. SCALE 1 IN. = 1 SEC SPEED 28 SEC = ¼ MILE.

Fig. 2. LONGITUDINAL MOTION. LOCOMOTIVE No. 115 SCALE 1 IN. = 1 SEC. SPEED 28 SEC = ¼ MILE.

Fig. 3. LONGITUDINAL MOTION LOCOMOTIVE No. 94 SCALE 1 IN. = 1 SEC. SPEED 35 SEC. = ¼ MILE.

different locomotives, ought to give valuable and accurate information about their vibratory movements. Carriages may be tested in a similar manner.

In short, the instrument furnishes a log of the run of a locomotive; it automatically records irregularities in the track, and it shows whether a carriage is running easily, or a locomotive is working safely and economically.

The Paper is accompanied by seven sets of small scale tracings, from which Plates 2 and 3 and the *Figs.* in the text have been engraved.

APPENDIX.

Locomotives in Japan.

No. 95 *Engine Class.*—There are ten of this class on the Northern Division; cylinders 15 inches diameter by 22 inches stroke; a 4-foot wheel; six wheels coupled.

Trailing 132 lbs. + driving 124 lbs. + leading 132 lbs. = 388 lbs., total on crank-pins, or equivalent balance.

Reciprocating parts on one side are:—

	Lbs.
Side-rod, complete	289
Connecting-rod, complete	175
Slide-blocks, cross-head, and small-end pin	129
Piston, complete	148
Total	741

No. 102 *Engine Class.*—There are two of this class; ten-wheel tank engine; six wheels coupled. Bank engines. Cylinders, 16 inches diameter by 22 inches stroke; wheels 4 feet diameter; pressure 160 lbs.

Trailing, 120 lbs. + driving 120 lbs. + leading 120 lbs. = 360 lbs. total on crank-pins, or equivalent balance.

	Lbs.
Side-rod, complete	400
Connecting-rod, complete	118
Pump-holder, two slide-blocks, one cross-head small-end pin	199
Piston, complete	209
Total weight on one side of reciprocating parts	926

Diagrams have been taken on No. 104.

No. 141 *Engine Class.*—Radials; four wheels coupled with a radial wheel at either end, with a total lateral motion of 2¼ inches; cylinder 14 inches diameter by 20 inches stroke; wheels 4 feet 4 inches diameter.

Type A.—Trailing 256 lbs. + driving 200 lbs. = 456 lbs., total on crank-pins, or equivalent balance.

	Lbs.
Connecting-rod, complete	160
Side-rod, complete	171
Two slide-blocks	44
One cross-head	72
Small end pin and cotter	10
Piston, complete	128
Total reciprocating parts	585

Type B.—Trailing 165 lbs. + driving 155 lbs. = 320 lbs. total on crank-pins, or equivalent balance.

	Lbs.
Connecting-rod, complete	150
Side-rod, complete	165½
Piston, complete	133½
Two slide-blocks, cross-head, and pin	101
Total reciprocating parts	550

No. 35 *Engine Class.*—These are four-wheels-coupled tender-engines. Cylinders, 15 inches diameter by 22 inches stroke; wheels, 4 feet 6 inches.

Trailing 262 lbs. + driving 246 lbs. Total on crank-pins 508 lbs., or equivalent balance.

No. 77 *Engine Class.*—These are six-wheels-coupled tank-engines for ballasting work. Cylinders, 13 inches diameter by 20 inches stroke; wheels, 3 feet diameter. It was found on a trial trip that the vibrations of these engines were extraordinary, and it was decided to take off the balance-weights and put on heavier ones.

Equivalent balance as originally sent out:—

Trailing 37 lbs. + driving 14 lbs. + leading 37 lbs. = 88 lbs.

The balance-weight taken off each wheel was 78 lbs., or a total of 234 lbs.

Equivalent balance as altered:—

Trailing, 90 lbs. + driving 71 lbs. + leading 90 lbs. = 251 lbs.

The new balance-weights weighed, before putting in place, 205 lbs. per wheel. There was no room for more weight, but after this there was a marked improvement.

	Lbs.
Small end-pin, cross-head, slide blocks, and cotter . .	81½
Piston	108½
Leading side-rod	135½
Trailing ,, ...	90½
Connecting-rod	126½
	542½

These engines still appear to be under-balanced.

No. 31 *Engine Class.*—Four-wheels-coupled tender-engines. Cylinders 15½ inches by 22 inches stroke; wheels, 4 feet 6 inches diameter.

Trailing, 145 lbs. + driving 301 lbs. = 446 lbs. on crank-pins, or equivalent balance.

	Lbs.
Piston, complete	169
Connecting-rod, complete	201
Side-rod, complete	156
Cross-head and slide-blocks	83
Weight of reciprocating parts	609

No. 1 *Engine.*—"The first and only one," built in 1871, and now working on the Kobe section. Cylinders, 12 inches by 18 inches stroke; wheels, 4 feet 3 inches diameter. Four-wheels-coupled tank-engine.

Trailing, 15 lbs. + driving 210 lbs. = 225 lbs. on crank-pins or the equivalent balance.

	Lbs.
Connecting-rod, complete	132
Side-rod, complete	108
Piston, ,,	71
Cross-head and slide-blocks	40
Small end pin	8
Weight of reciprocating parts	359

No. 13 *Engine Class.*—There are six of these engines, built also in 1871. They are four-wheels-coupled tank-engines. Cylinders, 12 inches diameter by 17 inches stroke; wheels, 4 feet 3 inches diameter.

The balance of these engines is as follows:—

Equivalent balance: trailing 150 lbs. + driving 150 lbs. = 300 lbs. on crank-pins.

	Lbs.
Connecting-rod, complete	104½
Side-rod, complete	119
Cross-head and slide-blocks	50
Piston, complete	96½
Total reciprocating parts	370

No. 9 *Engine Class.*—There are two of these engines, four-wheels-coupled tank-engines. Cylinders, 12 inches diameter by 18 inches stroke; wheels, 4 feet 6 inches diameter.

The balancing is as follows:—

Trailing, 120 lbs. + driving 303 lbs. = 423 lbs. on crank-pins.

	Lbs.
Connecting-rod, complete	93
Side-rod, complete	106
Piston, complete	133
Cross-head, two slide-blocks, and small end pin	87
Cross-head cotter	1½
Total reciprocating parts	420½

TABLE I.

Engine Class.	Reciprocating Parts.	Equivalent Balance.	Difference.
95	741	388	+353
102	926	360	566
141 (Type B) . .	550	320	230
141 (Type A) . .	585	456	129
35	601½	508	93½
77	542½	88	454½
77[1]	542½	251	291½
31	609	446	163
1	359	225	134
13	370	300	70
9	420½	423	−3½

[1] Re-balanced in Japan.

Table II.

Consumption of Coal per Mile.

1889. Month.	Number of Engine.	Type.	Miles.	—	Lbs. per Mile.	Average of Type.	Location of Engine.
February .	121	B	2,195	518	26·43	..	Kodzu.
" .	137	"	2,494	635	28·52	..	Yokohama.
" .	139	"	2,090	521	27·92	..	"
" .	143	"	2,348	599	28·57	27·86	
" .	129	A	2,802	592	23·66	..	Yokohama.
" .	131	"	2,946	643	24·44	..	"
" .	133	"	2,846	586	23·06	..	"
" .	135	"	2,461	530	24·12	23·82[1]	"
March . .	121	B	2,407	546	25·41	..	Kodzu.
" . .	137	"	2,828	588	23·30	..	Yokohama.
" . .	139	"	1,310	318	27·00	..	"
" . .	143	"	2,280	553	21·16	24·22	
" . .	129	A	3,293	750	23·70	..	Yokohama.
" . .	131	"	3,702	752½	22·77	..	"
" . .	133	"	3,193	694	24·22	..	"
" . .	135	"	3,559	646½	20·35	22·74[2]	"
April . .	121	B	2,520	612	27·70	..	Kodzu.
" . .	137	"	3,718	669	20·15	..	Yokohama.
" . .	139	"	3,960	725	20·51	22·80	"
" . .	129	A	2,528	621	23·50	..	Kodzu.
" . .	131	"	1,514	291	21·53	..	Yokohama.
" . .	133	"	3,814	691	20·29	..	"
" . .	135	"	3,505	617	19·72	21·26[3]	"
May . .	137	B	4,571	843	20·65	..	Yokohama.
" . .	139	"	2,920	683	26·19	23·42	"
" . .	129	A	2,960	665	25·15	..	Kodzu.
" . .	131	"	3,774	693	20·50	..	Yokohama.
" . .	133	"	2,916	601	23·46	..	"
" . .	135	"	3,863	649	18·81	21·98[4]	"
June . .	131	A	3,453½	657	21·31	..	Yokohama.
" . .	133	"	2,621½	507	21·66	..	"
" . .	135	"	3,896	645	18·54	20·50	"
" . .	137	B	3,348	660	22·08	..	"
" . .	139	"	2,822¾	637	25·27	23·67[5]	"

[1] 4·04 lbs. per mile in favour of A.
[2] 1·88 " " " "
[3] 1·54 " " " "
[4] 1·44 " " " "
[5] 3·17 " " " "

TABLE III.

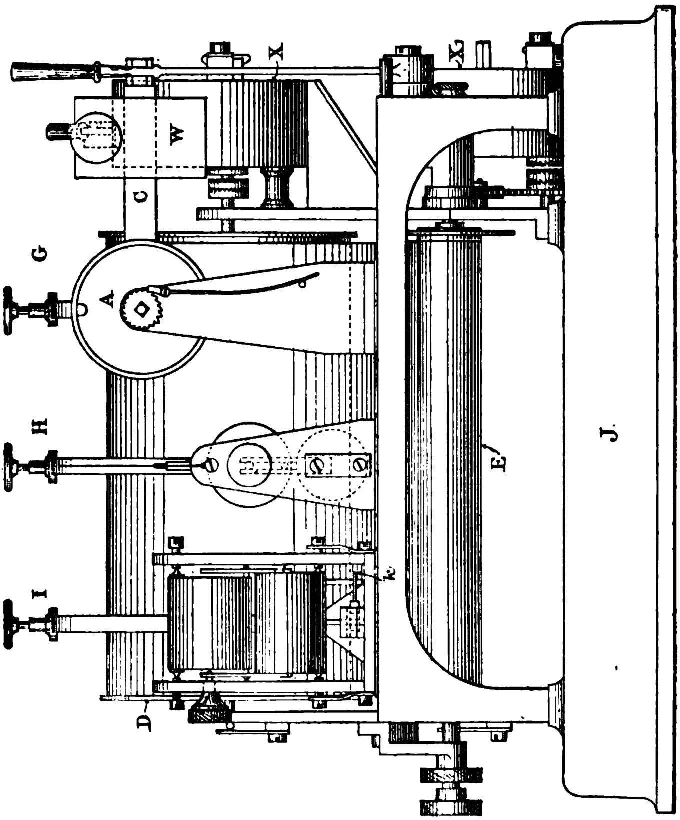
Month.	Miles.	Lbs. per Mile.	No. of Engine.
February	2,635¼	10·75 (?)	9
„	2,944	18·46	11
„	2,642½	25·34	102
„	2,030¾	51·24	104
„	990¾	29·10	93
March	4,026¼	17·98	9
„	1,700	15·65	11
„	2,962¾	33·40	102
„	2,634½	31·71	104
„	2,635	41·53	93
April	4,529¾	14·67	9
„	1,755½	19·46	11
„	2,547½	46·07	102
„	1,450	28·04	104
„	2,942	32·94	93
May	4,152½	15·56	9
„	4,163	17·25	11
„	4,600	44·42	102
„	4,010	50·71	104
„	2,544¾	40·26	93
June	3,291½	14·96	9
„	4,163	15·06	11
„	3,049¼	41·72	102
„	3,010½	41·65	104
„	2,506	27·41	93

Discussion.

Sir John Coode.

Sir JOHN COODE, President, said that the Paper just read was one of no ordinary value, for it afforded an insight into the action of locomotive engines upon the permanent way such as would be attended with beneficial results to the working of railways under all conditions. He was sure, therefore, that the members would desire to convey their very best thanks to the Authors.

Fig. 4.

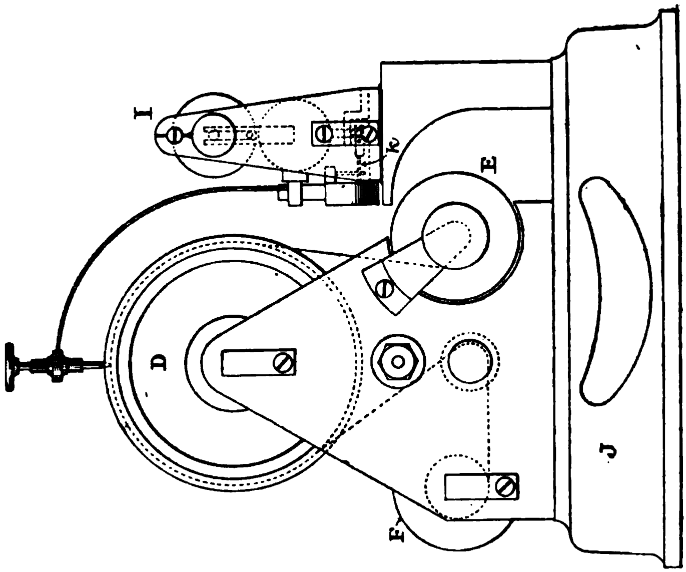


SIDE VIEW.
Scale 4 inches = 1 foot.

Mr. BRACEBRIDGE MILLS said that during October and November 1889, he had made a few journeys with one of Professor Milne's vibration recorders, one of the first constructed in this country. It was a triple instrument for registering vertical, transverse, and longitudinal motion, and was represented by *Figs. 4, 5, 6.*

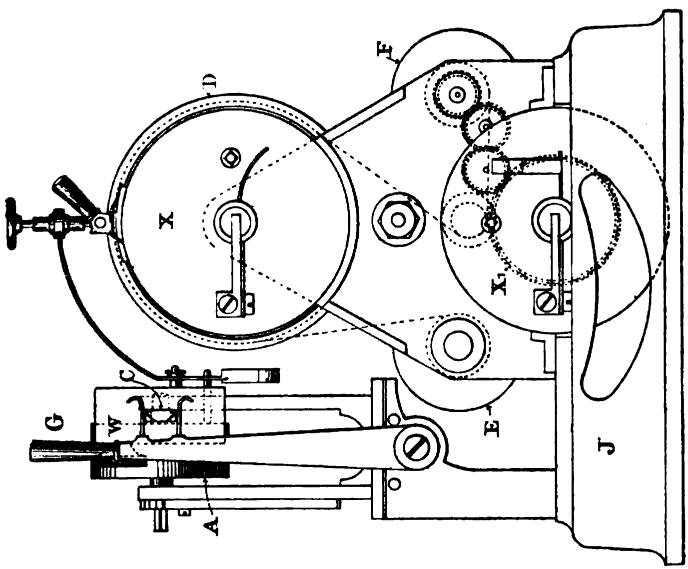
Mr. Mills.

Fig. 6.



END VIEW, LEFT HAND.
Scale 4 inches = 1 foot.

Fig. 5.



END VIEW, RIGHT HAND.
Scale 4 inches = 1 foot.

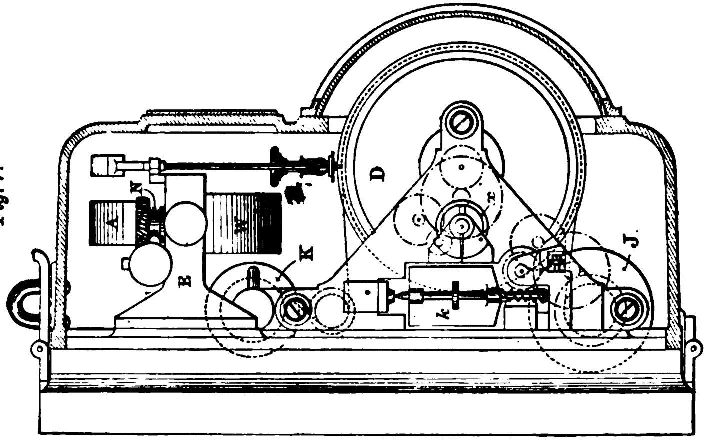
Mr. Mills. Although that form of apparatus was now obsolete, or only recommended for use under special conditions, he would briefly describe its construction in order that the nature of certain modifications in the present form of instrument, and the reasons which led to their introduction, might be more readily understood. G was the system for recording vertical motion, A being a box containing a coiled spring, attached to which was an arm C, carrying a weight W to balance the moment of the coiled spring. The system H, which was on the same principle as that shown in Fig. 8, Plate 2, was for recording transverse motion, and the system I, for recording fore-and-aft motion, was similar to H, but set at right angles to it, the pencil being made to write in the same plane as that of H by the intervention of a bell-crank lever *k*. D was a drum 12 inches in circumference rotated by the clock X at a uniform speed of 1 revolution per hour. E was the reserve coil of paper, the free end of which was taken over the large drum D, and secured to the winding roller F, upon which the diagram was coiled by means of the clock X_1. The instrument was mounted on a somewhat heavy cast-iron base J, so that it would stand firmly on the floor of a carriage without being secured by screws or other fixings. He had on two occasions travelled with this instrument to Hastings and back by the South Eastern Railway from Cannon Street station, and obtained some very interesting diagrams, which were being exhibited in the library. On the whole the instrument recorded very satisfactorily, but it appeared at times to be too sensitive, and probably, under abnormal agitation, its records might not be taken to measure or compare with the actual motions of the coach. For obtaining general information respecting the condition of the permanent way, however, he did not think that that was of much importance; the information was in his opinion sufficient if it showed that a defect in the permanent way existed at a certain point, without ascertaining the exact range of movement imparted to the coach or locomotive. He changed trains at Sevenoaks; and he wished to draw attention to the difference in the fore-and-aft motion recorded by the instrument, it being much greater between London and Sevenoaks than between Sevenoaks and Hastings. As the irregularities in the permanent way produced very little, if any, fore-and-aft motion, he suggested that the engine employed between London and Sevenoaks was not so perfect in its balancing as the one which took the second train from Sevenoaks to Hastings. He could not account for the difference in any other way. Curves and gradients were distinctly recorded on the diagrams exhibited. At increased speeds, and when the

range of the transverse motion was great, that part of the instrument did not appear to record so accurately. He did not, however, think that this result pointed to faulty principles in the vibration recorder, but simply showed that the particular one employed was unsuited for such a great range of motion. There must obviously be a limit in each case to the amplitude of oscillation which could be recorded with accuracy, and on this occasion he was using it beyond that limit. Professor Milne, he believed, had found that the instruments which in Japan had been successful in producing accurate diagrams, were quite unsuited to American and European lines. In Japan the working speed was from 25 to 30 miles an hour, whereas in England, America, and on the Continent, the speeds which had to be dealt with were about twice as great, as were also the oscillations, and it was for this reason that it had been necessary to modify somewhat the Milne-McDonald apparatus. The speed, of course, affected the width of the diagram, and determined in a great measure the useful range of motion required in the instruments. Before introducing to the notice of the meeting the improved forms of vibration recorder which he had brought with him that evening he would briefly refer to the limit of accuracy in the original instruments. There was a limit to the accuracy of the recording mechanism—the pencil and its supports, and also to the indicating system—the cylindrical pendulums A and B, Fig. 8, Plate 2. The Authors had given a Table showing the relative proportions existing between the range of actual motion imparted to the instrument, and that registered on the diagram, and by referring to that Table it would be seen that, in the case of transverse motion, the pencil recorded only half the actual motion of the coach or locomotive when this exceeded about 5 millimetres. The main cause for the relative diminution in the records as the range of oscillation increased was, he thought, to be found in the method of writing the diagram; for by reference to *Figs. 4, 5, 6*, it would be seen that the pencil moved in a circular path whilst the diagram was written on a straight surface. Such a method was very suitable so long as the range of motion was small, as in Japan, where the speeds were slow and the lines particularly well constructed; but it had shown itself unsuitable for great speeds, inasmuch as abnormal motion was not so faithfully recorded as the normal swing of the coach or locomotive at that speed. For ascertaining the condition of a line it was the abnormal motion, or jerks, which it was desired more particularly to register, and it was by the position and magnitude of these excrescences on

Mr. Mills.

Mr. Mills.

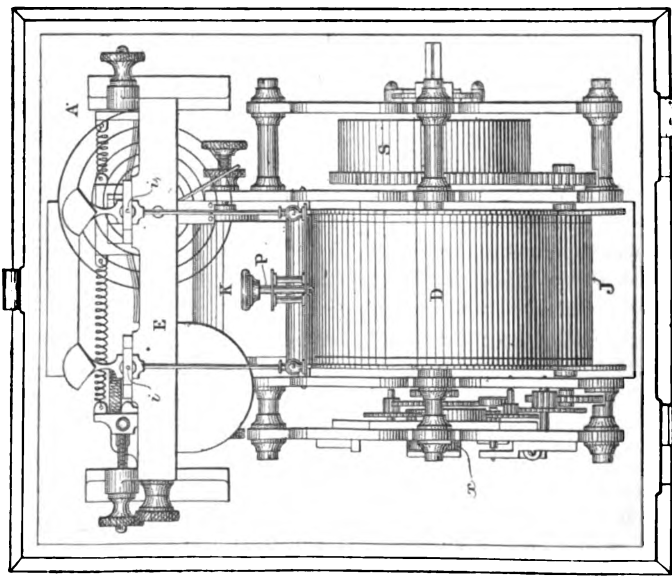
Fig. 7.



Side Elevation, Cover in Section.

Scale 4 inches = 1 foot.

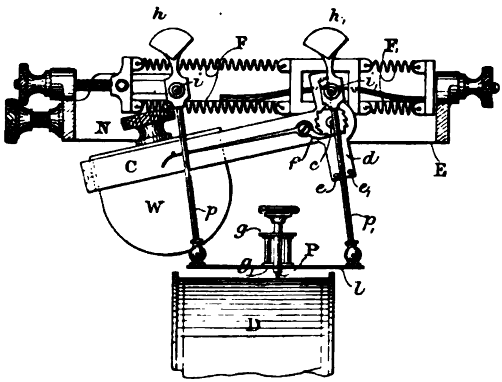
Fig. 8.



Front Elevation, Cover Removed.

the diagram that faults in the permanent way were located. In the latest forms of the instrument a modified arrangement of the rocking arm or beam (C, *Fig. 4*) and the pencil gear, suggested by himself, had been adopted. He was able to exhibit two of those instruments to the meeting, one of which was upon the table, the second being fixed to a vibrating board in the library. The one upon the table was represented in *Figs. 7, 8, 9*, and was for recording vertical motion only. It would be seen that the pencil remained in a vertical position under all circumstances, and as its centre of motion was some distance from the point at which the diagram was written, the curtailing of the diagram under abnormal motion was greatly reduced. Great vertical Mr. Mills.

Fig. 9.



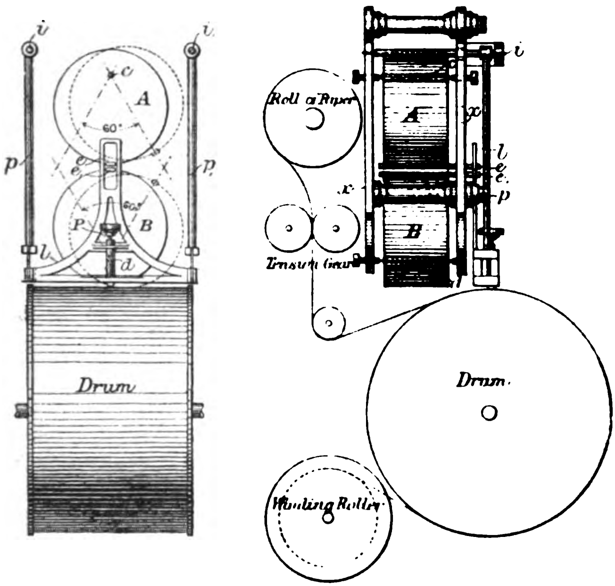
Scale 4 inches = 1 foot.

rigidity was given to the pencil gear by such an arrangement. C was the rocking arm or beam turning on hard steel centres at *c*. W was the weight capable of being clamped by the nut N at varying distances along C from the centre *c* in order to increase or decrease the magnification of the instrument. The spring A had its inner end attached to the arbor or spindle working on centres *c*, and its outer end secured to the fixed frame E; it was capable of being "set up" the requisite amount to balance the weight W by means of the rachet and pawl *f*. F F_1 were the compensating springs, the function of which was the same as that of the spring D, Fig. 1, Plate 2. The pencil suspension-rods $p\,p_1$ worked freely about the centres $i\,i_1$, and were connected at their lower extremities by knuckle-joints to the link *l*, carrying the pencil P, which, being made to slide freely in the guides $g\,g_1$, rose and fell

Mr. Mills. so as to maintain contact by its own weight with the travelling strip of paper. The fan-shaped weights $h\,h_1$ were extensions of the suspension-rods $p\,p_1$, and were employed to balance the moment of the pencil and its supports; in other words, to bring the centre of gravity of the system into a line with the centres of suspension $i\,i_1$, in order that the instrument might not be affected by the horizontal component of the motion. The oscillatory movements of the beam, relatively to the fixed parts of the instrument, were imparted to the recording gear by means of two steel pins $e\,e_1$ projecting at right angles from the arm d forming part of the beam C. J was the pulling or coiling roller driven by the spring barrel S, its speed being controlled by a fan k. D was the drum rotated by the friction of the moving paper, and timed by means of the escapement x to make one complete revolution per hour. K was the reserve coil of paper. The whole instrument was mounted on a cast-iron back-plate, and protected by a thin cast-iron cover with semicircular brass bezel and plate-glass, so as to effectually exclude dust and damp. The cover was swung on detachable pin hinges at the bottom, and secured by an ordinary padlock at the top. This instrument could be used to measure vibrations to a much greater range than that shown in *Figs.* 4, 5, 6; it was more sensitive to slow motions of short range and at the same time more nearly dead-beat. It was one of the commercial forms which it was proposed to manufacture in this country. Returning to the triple instrument, and referring particularly to the systems for registering horizontal motion, he had already stated that there were two things which determined the limit of accurate recording. He had dealt with one of them, namely, the means adopted for writing the diagrams. The second related to the size of the cylindrical pendulums and the way in which they were connected. He had found that with the instrument shown in *Figs.* 4, 5, 6, a horizontal motion of about 10 or 12 millimetres was the greatest which could be accurately recorded. From his experiments during the past twelve months over various lines, and under varying conditions, it seemed evident that the system for recording horizontal motion needed modification to enable it to respond with a similar degree of accuracy to oscillations of varying and extended range. This was especially required for car and locomotive testing, where it was necessary for an instrument not simply to announce that an abnormal movement in a certain direction had occurred, but to measure that motion with a fair degree of accuracy. *Fig.* 10 illustrated a modification of the Milne-McDonald instrument which he had designed, and which was now adopted when an

extended range of motion was required. A B were the cylindrical pendulums pivoted at $c\,d$ in the frame x. The pencil gear was somewhat similar to that in the vertical instrument, *Figs.* 7, 8, 9. $p\,p_1$ were the suspension-rods swinging on centres $i\,i_1$ and connected at the bottom by the link l, which was continued upwards at the back of the pencil P, and provided with a slot in which the pins $e\,e_1$, projecting from the circumference of the cylindrical pendulums A B, worked. In other respects this instrument resembled that shown in *Figs.* 7, 8, 9, the only difference in the Mr. Mills.

Figs. 10.



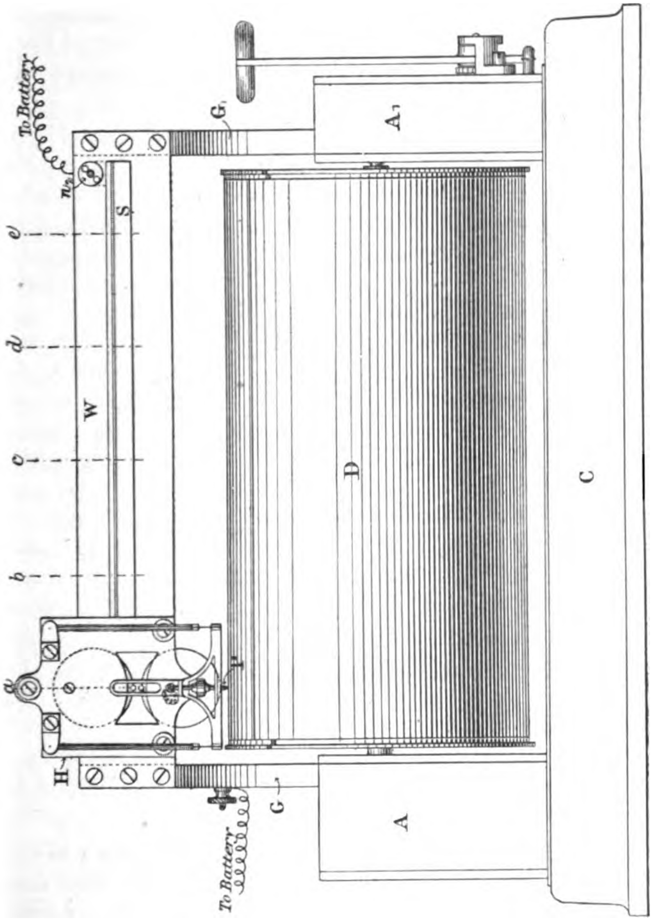
Scale 4 inches = 1 foot.

two being that the rocking beam and weight in *Figs.* 7, 8, 9, was replaced by a horizontal recording system in *Fig.* 10. This instrument had worked perfectly, and, by reason of the new method of communicating the motion of the pendulums to the pencil, the useful range had been trebled; in fact the diagrams could be used to measure oscillations up to 35 millimetres on a level road. Even at such a great range of motion he had failed to detect any inaccuracies in the records by the system tending to acquire a periodic swing of its own. During August and September 1890 he had taken the instru-

Mr. Mills. ments to the north of England and Scotland, obtaining some first-rate diagrams on the North British, Caledonian, London and North Western, Furness, and Midland railways. (Some of the diagrams referred to were exhibited.) One of these, to which he wished to call special attention, was that of a journey from Manchester to London by the Midland 1.20 P.M. express; and it was, he thought, a wonderfully characteristic diagram of the line. All the familiar shocks could be easily recognized, and the shaking commonly felt when emerging from Dove Holes tunnel near to Peak Forest Station where the down-grade commenced, was very distinctly marked. He had two vertical-motion recorders placed side by side in one box, which was placed on the floor of the Pullman car, and he was thus able to watch and compare the working of the two instruments. Throughout the journey they both acted extremely well, in fact it would be difficult to imagine how their working could have been improved. It was most interesting to watch the apparent oscillations of the two beams. They moved—relatively to the fixed parts of the instrument—perfectly in unison; and so synchronous was the motion that one might have imagined the two linked together by some invisible mechanism. That which the Authors had referred to as the "multiplication" of the instruments differed in the two machines he was using; as did also the speed at which the paper travelled in them. Notwithstanding those differences both in the longitudinal and transverse dimensions of the diagrams, corresponding disturbances might be easily traced. The shapes of the two agreed. When travelling on the Furness Railway from Whitehaven to Preston, which runs along the coast of Cumberland and Lancashire in a succession of sharp curves, and crosses the Duddon, Cartmel, and Lancaster sands, the instruments had a very severe test; indeed, he could not imagine any line where they would be more severely tested. They nevertheless worked very well under the circumstances. Curves when being traversed at a high rate of speed had a certain disturbing influence on the accuracy of the records, owing to the action of centrifugal force, the diagrams being generally larger in such cases. That might, however, be thought a valuable feature of the instruments, as the diagrams were in some degree a measure of that force. He was never able to detect any error due to the beams acquiring a periodic swing of their own—a fact which he considered of the greatest importance, but he had often noticed that an abnormal motion was recorded which he himself did not perceive until its presence was announced by the instrument. This showed that the vibration

recorder was much more sensitive to changes in position and slow movements than the observer, a peculiarity of the apparatus which was often manifested when crossing bridges and swampy lands. He regretted being unable to exhibit to the meeting Mr. Mills.

Fig. 11.

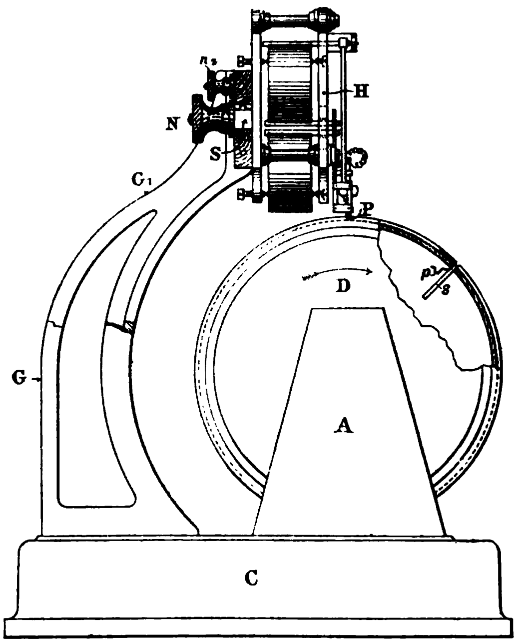


Scale 3 inches = 1 foot.

one of the instruments designed by Professor Milne for the purpose of determining the jerkiness of locomotives due to faulty balancing, and the motions of different types of carriages. He had, however, placed on the wall a diagram prepared from a working drawing of one of them. In *Figs. 11, 12,* D represented

Mr. Mills. the drum, 20 inches in circumference, rotated, at a uniform speed of one revolution in twenty seconds, by clockwork concealed within the pedestals, A A_1. G G_1 were light cast-iron supports carrying the horizontal recording-system H, which was made to slide along the surface of W, and was capable of being clamped in any position by the lock-nut N. It had been suggested to use electrical means for recording the relative movements of the pencil P and the drum D. For that purpose chemically prepared paper

Fig. 12.



Scale 3 inches = 1 foot.

was employed, and the current from a small battery was made to pass through the paper from the pencil—which in that case was merely a hard steel point—to the drum D, the path traversed by the point being indicated by the appearance of a coloured stain on the paper. Such a system of writing the diagrams had, he thought, many advantages; the writing-point required no attention, such as sharpening, or supplying with ink, as was the case when pencils or pens were used. The friction on the paper was very small, and thus the instrument was made more sensitive—a matter

of great importance for locomotive testing. Lastly, the instrument did not write until the moment it was required to make a diagram, when the operator had only to depress the battery-key. The battery was fitted in the carrying-box of the instrument, and it was not necessary to remove either from it in order to make a test. When a diagram had been obtained with the recording system in position *a*, the lock-nut N was slackened, and H pushed along the slot S to position *b*; a second test could then be made, and the recording system again shifted, so as to occupy the positions *c*, *d*, *e*, successively producing in all five diagrams side by side on one sheet of paper. By using the electrical means of writing, it was rendered unnecessary to stop the drum during the five experiments. This was of some importance; for when pencils were used the drum had to be stopped and re-started at each test, and consequently never acquired a really constant velocity. Before concluding his remarks on Messrs. Milne and McDonald's apparatus, he would say that from the year's experience he had had, his opinion was that they were thoroughly reliable instruments for recording the oscillations of railway carriages and locomotives; but it had of course been found necessary to somewhat modify the original patterns made by Professor Milne in Japan, as the conditions of working there and here were quite different. As to the many uses to which the vibration records could be applied, some of which had been indicated by the Authors in their very interesting Paper, that was a branch of the subject which he must leave to be discussed by those who were more intimately acquainted with the requirements of the railway engineers than he was himself. The Western Railway Company of France appeared long since to have recognized the value of the information given by such diagrams. At the Paris Exhibition instruments were shown which had been in use on their line since 1879 for recording the motion of locomotives. The system differed greatly from that suggested by the Authors of the Paper. They measured the relative motion of the foot-plate of the locomotive and one of the leading axle-boxes; in other words, the vertical motion of the spring. The apparatus consisted of a lever, one end of which was attached to the top of the spring-box, and the other was connected with a stylus pressing against a plate or cylinder. The cylinders were of zinc, coated with a protective varnish, which was scratched away by the rubbing of the stylus. At the end of the journey the cylinders were removed from the instruments, and treated with acid, when the parts laid bare by the rubbing of the stylus were eaten in. From the time the instruments had been used, it would appear Mr. Mills.

Mr. Mills. that they had given satisfaction, but, in his opinion, they must have been somewhat inaccurate, because the motion recorded was one compounded of the motion of the spring-box, and the whole vibration of the engine; it was not a simple motion. The diagrams were not to be compared with those produced by the instruments of Messrs. Milne and McDonald, and they were very difficult to read. He understood that the London and North Western Railway Company had also taken the matter up. Last year he had had the pleasure of showing one of the Milne-McDonald instruments to Mr. Footner, who had told him that the company had carried out an elaborate series of experiments, as to which, perhaps, the Institution would receive some information. In 1883 a very complete series of experiments was conducted on various lines in Germany by, he believed, Mr. Klose for the Society of German Railway Engineers. The object of those experiments was to determine the difference in the oscillations of carriages when linked axles, coupled or independent, or rigid axles were used. The apparatus employed, which was for recording motion in a horizontal plane only, appeared to him to have been rather complicated; and as the instrument consisted of a specially constructed coach, it must have been very costly. The under frame of the coach to be tested was connected by a steel wire to the instrument-car in front of it; the horizontal motion of the wire being imparted to a system of levers under the instrument-car, which in turn gave motion to the pencil of the recording instrument. The diagrams were written on strips of paper similar to those employed in the Milne-McDonald instruments. There was a striking resemblance in the records of the two instruments. Although these experiments appeared to have been crowned with a marked degree of success, furnishing valuable information, and, he believed, creating great interest among railway engineers at the time, they nevertheless appeared to possess the same element of inaccuracy as had existed in the experiments of the French company. The motion recorded was not a simple one; but must necessarily have been the motion of coach compounded with that of the instrument-car itself. An American engineer, whose name he could not remember, had also constructed apparatus for a similar purpose. Professor Milne had informed him that when in the United States last year he had called at that gentleman's office hoping to obtain an interview, but was informed that the engineer referred to would not be visible for some time, being engaged *inside* his instrument. From that he (Mr. Mills) thought that it might be safely concluded that the instrument in question was not a portable

one. His object in referring to these experiments was merely to draw attention to the difference there existed in the apparatus used on those occasions and the vibration recorders then before the meeting. In one case they had either specially-constructed coaches, costing probably some hundreds of pounds, or else instruments necessitating structural alterations to existing coaches and locomotives before they could be applied. In the second case, they had small portable self-contained instruments, which at a few moments' notice could be prepared for a test, and could be as readily used on one carriage or locomotive as upon another. These, he ventured to think, were advantages possessed by the Milne-McDonald instruments which could not fail to be appreciated by those whose duty it might be to use such apparatus. Mr. Mills.

Mr. R. M. Moir said he presumed that the invitation he had received to attend the meeting was due to the fact that he had been in close correspondence with Professor Milne with regard to the instrument described in the Paper. He perhaps looked at the matter from a different point of view from that of many present, who dealt with the subject technically. He thought that the instrument was practically of very little use, unless those who had to pay for railways, and to get dividends from them, could ascertain that by the employment of it the condition of the road could be carefully watched, working expenses reduced, and dividends increased. Professor Milne had been giving his attention to that subject. The work which Mr. Bracebridge Mills had so ably carried out in designing and superintending the construction of the models, had been very interesting, and he had watched it as closely as it was possible for a non-technical man to do. He had also had the benefit of the advice of a very practical friend, Mr. Connell. When the instrument on the table was constructed last year he had put it in charge of Mr. McQueen, an engineer now in Persia, in order that he might take it to Glasgow and exhibit it to Sir William Thomson, who had taken a very warm interest in the subject from the outset, and who had expressed his opinion that the vibration-recorder had a future before it. Mr. McQueen had to sit watching the machine all the way from London to Glasgow. As far as he (Mr. Moir) could judge the machines already constructed were only of value to an engineer who could sit in his testing-car and watch the diagram as it was rolled off on the cylinder and follow it very closely. The diagram which he held in his hand was, he believed, one of the most perfect that had been taken. At a very early period an engineer pointed out to him that the instrument had a serious defect from a practical point of view, Mr. Moir.

Mr. Moir. because it did not record the speed at which the train was travelling. Mr. Moir did not place any great reliance upon a diagram taken on such a short journey as that from Yokohama to Tokyo, where the train had scarcely started before it had to slow down again. Until the machine had been used on a long-running line, it could hardly be of much value in testing the conditions of the road. But if it was used in its present form in a train running for any considerable distance of course it only told the time during which the train was in motion. If an engineer brought him a diagram and said that the train had been in motion so long, and that a weak point was shown upon the diagram where a girder or a bridge had deflected too much, he should ask to be shown the point where it was likely to have taken place, and the speed at which the train was travelling. Knowing the speed at the time at which the vibration took place it would be possible to ascertain within a $\frac{1}{4}$ or $\frac{1}{2}$ mile the place which required attention. That was a point to which Professor Milne had been giving very earnest attention, and he had sent to Mr. Moir the plan of an apparatus which he had designed for use in Japan whereby the speed of the train could be recorded on the diagram. The drawing was at present incomplete, and he could not, therefore, exhibit it. He had, however, placed it in the hands of a practical engineer, who had expressed his opinion that the instrument would act, but recommended a more simple plan by which the same thing could be accomplished, and any effect on the working of the instrument due to the putting on of the brakes would be counteracted. The drawings of the latter proposal would be sent out to Professor Milne, and until he and Mr. McDonald had expressed their opinion upon it it would be unwise to give it publicity. Some of the diagrams taken last year by Professor Milne had been kindly received by two or three engineers of English railways, and in one instance where a weak point in the line had been indicated by the diagram, the engineer had stated that that was the very point to which they were at that moment attending, in the belief that there was something wrong in the ballasting. One engineer had remarked that he did not know whether these particulars would be always welcome to him, because it would not suit him to have his directors coming and telling him that the instrument had shown a part of his road to be faulty. Another point to which Professor Milne had been directing his close attention was one which Mr. Moir could not quite appreciate except so far as it related to the fact that an engine might be made to burn less coal and do less damage to the permanent way: he referred to the testing of loco-

motives. Writing from Tokyo, on the 2nd of August, Professor Milne had stated that the quick running type was being used for the testing of balancing; and enclosed tracings of portions of diagrams from two sister engines and an American engine. He added: "In consequence of diagram from No. 138, this locomotive is now being altered; it tends to break the couplings, &c., and is certainly dangerous." He had also sent a set of diagrams, which he believed to be of commercial value. No. 138 engine, he said, as altered, could now be run safely at forty miles; before it was dangerous at thirty, and more than once broke the draw-bars. It would now run about one mile further without steam, and it burnt less coal than formerly. The instrument at present employed by Messrs. Milne and McDonald, in Japan, appeared to be somewhat simpler in detail than that which had been constructed by Mr. Bracebridge Mills. He thought it would be unwise to pass the instrument at once into commercial use, or ask any firm to undertake its manufacture until Professor Milne and Mr. McDonald knew the result of that evening's discussion, and had fully considered an elaborate report presented by Mr. Bracebridge Mills, together with other criticisms which had been offered by engineers, all of which would be sent to Messrs. Milne and McDonald, who would then decide as to the form of instrument they would ultimately adopt. For his own part he did not think the vibration-recorder would be of much value until it could be put into the guards' van by an assistant, before an express train started, and then locked up, to be taken out by another assistant at the end of the journey, when it would tell its own tale as to what had occurred during the transit. There was one remarkable circumstance to which Professor Milne did not refer in his Paper, and probably it had not come within the observation of Mr. Bracebridge Mills, namely, that when brakes were put on to a train rather suddenly, there was a corresponding mark on the diagram in the nature of a wavy line. If the speed at which the train was travelling could be recorded, they might by means of that indication be able to tell within a few yards where the brakes were applied. They could also tell by the diagram which he had placed on the table, the places where the train had been stopped by signal. He had shown it to the President of an American railway, who said: "We have something of the kind by which we can record the speed of our locomotives, but this gives time, and the stoppages; it would be extremely useful, especially in the case of our freight trains out West, because it would act as a kind of automatic inspector. Some of our men run the trains Mr. Moir.

Mr. Moir. into sidings, go and see their wives and children, and then start again." If they could produce such records by means of the Author's instrument, he thought that a great boon would be conferred upon the engineering fraternity.

Mr. Shelford. Mr. W. SHELFORD said that Mr. Bracebridge Mills had referred to a run from London to Hastings and back, where he had found that much greater longitudinal motion was shown by the diagram of the instrument between London and Sevenoaks than between Sevenoaks and Hastings. It would be interesting to know whether on the return journey he had found the longitudinal motion greater between Hastings and Sevenoaks than between Sevenoaks and London. Mr. Shelford's impression was, that a great deal more was attributed in the Paper to the balancing of engines than ought to be. The Author had said, that the only difference between two of the engines he had referred to was in their balancing, and that difference was shown in Fig. 12A, the saving of coal in the one having the larger balance over the one having the smaller being about 14 per cent., which was attributed entirely to this cause. Other similar references were also made in the Paper. With regard to the run between London and Hastings, Mr. Shelford believed that Sevenoaks was the summit of the line, there being a rising gradient between London and Sevenoaks, and a falling gradient between Sevenoaks and Hastings, and *vice versâ* on the return journey, and he should expect to find that there was greater longitudinal motion in the engine when it was doing the greatest work, viz., on the up grade, irrespective of balancing. In that case if an engine ran through from London to Hastings or *vice versâ* without change, the instrument would indicate the greatest longitudinal motion when approaching the summit of the railway from either side. It was important to ascertain whether Mr. Bracebridge Mills' diagrams showed this to be the fact.

Mr. Mills. Mr. BRACEBRIDGE MILLS said that on the return journey he had not found that the fore and aft motion was greatest between Hastings and Sevenoaks. It was the only instance in which he had had to change trains at Sevenoaks, and he had never noticed the difference in the diagrams before or since. If the sudden alteration in the fore and aft motion was to be attributed to the cause suggested by Mr. Shelford, he (Mr. Mills) should have expected to find a characteristic diagram of the line repeated at every experiment. So far as he could remember, not having his diagrams before him, there had not been any such similarity of the diagrams. In the case of the test illustrated by *Figs. 30 & 31*, he believed that the range of the fore and aft motion of the loco-

motive when the balancing was defective varied between 12 and 20 millimetres. The diagram on the wall was enlarged about twelve times. Mr. Mills.

Mr. WILFRID STOKES said it would be advisable to have some information as to the position of the instrument in the train. If it were on the carriage next the engine many more pulsations might be expected than if it were in the guard's rear van. Moreover, the position of the instrument on the engine or in the carriage would have a marked effect on the resulting diagram. A record taken in the guard's van immediately behind one of Mr. Webb's compound engines would probably give some instructive information as to the action of the low-pressure cylinder. He hoped that the promised diagrams taken on the London and North Western Railway would contain the results of such experiments. He also thought that the system of draw-bars and springs and the tightness of coupling-up would greatly influence the indications of the vibration-recorder. Probably the best position for the instrument would be suspended from an axle, in which case it would be very easy to adapt it for recording distance. Mr. Stokes.

Mr. ALFRED J. HILL asked whether the Authors had tried placing the instrument in different portions of the train or of the locomotive. He thought it would be important to try one in front of the buffer beam, so as to get the motion of the leading wheels; and it might be interesting to have an experiment on two locomotives similarly constructed, but one having radial axle-boxes, and the other a bogie. Useful results also might perhaps be obtained if locomotives were tested with different arrangements of hanging springs, as india-rubber cushions had recently been inserted, in some cases, in addition to the ordinary steel laminated springs. Also locomotives were being built with volute springs of the Timmins, or some similar form, and it would be interesting to know the various results which would be recorded in each case by machines such as those described. He should be glad to know if particulars could be given with reference to the cylinders of the locomotives. The one shown in Fig. 12 had outside cylinders; but the Paper gave no information as to whether on the engines mentioned they were inside or outside. A good deal had been said about balancing locomotives, but nothing had been mentioned as to any experiments on carriages. Carriage wheels were now accurately balanced, and it might be well to have some diagrams taken on similar vehicles with true wheels and with wheels slightly out of truth, to see if any appreciable difference Mr. Hill.

Mr. Hill. was shown. Perhaps some information on these points might be obtained from the London and North Western Railway Company.

Mr. Marriott. Mr. W. MARRIOTT said he had taken great interest in the Paper, having had charge both of locomotives and of permanent way. About five years ago General Hutchinson remarked to him that there was no instrument which recorded the strain of a locomotive on the permanent way when the road was rough and the engine lurched. It now appeared that if the diagrams could be accurately measured they would show the strain coming on the rails in excess of the weight of the locomotive. Of course when an engine lurched, or as engine drivers said, "put its foot into a hole," there must be a considerable amount of strain on the permanent way which could not be recorded except by such an instrument as had been described. With regard to the question of balancing referred to in the Paper, he thought that a good deal too much was made of it. He could not follow the weights given, because of course balancing had to do with the distance of the centre of gravity of the crank-pin and reciprocating parts from the axle, as well as the distance of the centre of gravity of the balancing weight. He was inclined to think with Mr. Shelford that if a record had been taken from Hastings to London the diagram would have been much the same, showing that the difference was due rather to the engine being in collar, and pulling hard, than to the balance-weight. It was somewhat strange to put down the extra consumption of coal entirely to the defective balancing of the engine, for it was well known that engines of exactly the same type and coming from the same shops, sometimes showed a difference of 4 or 5 lbs. per mile in coal consumption, which was due perhaps to longer rods, or springs of a different height, or to a change of drivers. No doubt if a machine of the kind described could be locked up in an engine, or in a guard's van it would be a useful addition to the ordinary inspection of the permanent way.

Mr. Cowper. Mr. CHARLES COWPER asked whether it had been found possible to ascertain, from the character of the recorded vibrations alone, in any isolated case, where the fault was due to the engine, and where it was due to the permanent way. He imagined that it might be possible, but rather difficult. The value of the record appeared to him to depend upon comparison under equal conditions; thus, in order to test several lines or parts of a line, he thought that the instrument should, in each case, be placed upon the same part of the same engine (or carriage behind the same engine), with the same driver, the weight and length of the train and its speed being also the same. In like manner, when different

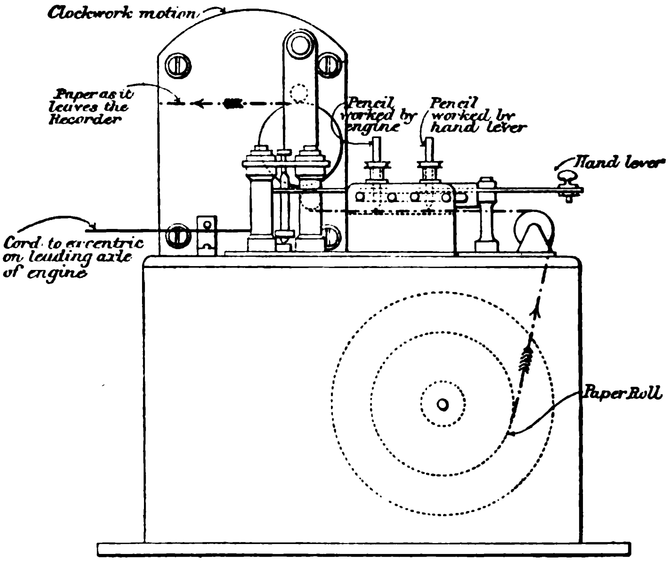
engines were to be tested, they should run on the same line, and under similar conditions in all other respects. Under such circumstances he thought that the tests might be extremely useful, but he did not think that a series of journeys in a tour over different railways, such as had been mentioned by Mr. Mills, could give any definite results, as the record would be a compound one, in which the faults of the rolling-stock would be mixed up with the faults of the permanent way. Mr. Cowper.

Sir Frederick Bramwell.

Sir FREDERICK BRAMWELL said the principle of the machines before them appeared to be identical with that of the well-known pedometer invented by Mr. Payne. Having sought in vain to find the instrument that his father had, and which he had used many a time, he thought that the next best thing he could do was to obtain the specification of the patent, dated 1831, and he would refer especially to Fig. 8 in that specification, which showed a weight held in a horizontal position by means of a wound-up spring, the implement containing it being carried in the waistcoat pocket. The rise and fall in walking produced a relative motion between the quiescent weight and the moving case, and in that way the number of steps was recorded, and the instrument being set for the particular step of the particular wearer, it showed the number of miles walked. The instruments now exhibited seemed to depend upon this same principle of the inertia of a weight in an apparatus, which apparatus was itself moved by the thing of which they desired to record the movement, and in that way from the inertia of the weight and the movement of the case the motion was obtained which was recorded. Payne's pedometer recorded only, by the movement of a hand on a dial, the number of miles walked, while the record in the instrument before them was graphic, giving not merely the sum of all the motions, but the individual motions, and in that sense it was useful for its purpose. Although he hardly liked to exhibit so coarsely made a piece of work in the presence of instruments of the beauty that were before them, it might be interesting to the Institution to see a brake-recorder which he devised a good many years ago, when the question of the Le Chatelier counter-pressure system of stopping trains was put before the Institution of Mechanical Engineers; this apparatus was made at that time by him, but in a very incomplete sort of way. He tried it on one occasion with the son of the late Mr. Beattie, and only on one occasion. Some years afterwards, when an inquiry into continuous railway brakes came before Mr. Cowper and himself, he had that same machine made in

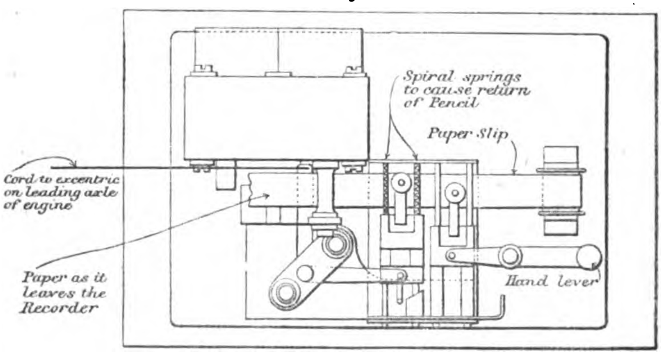
Sir Frederick Bramwell. the form in which it now appeared, and he put it to work with very great success. He had brought it forward because it was said on the last occasion that it would be well if a machine were

Fig. 13.



SIDE ELEVATION

Fig. 14.

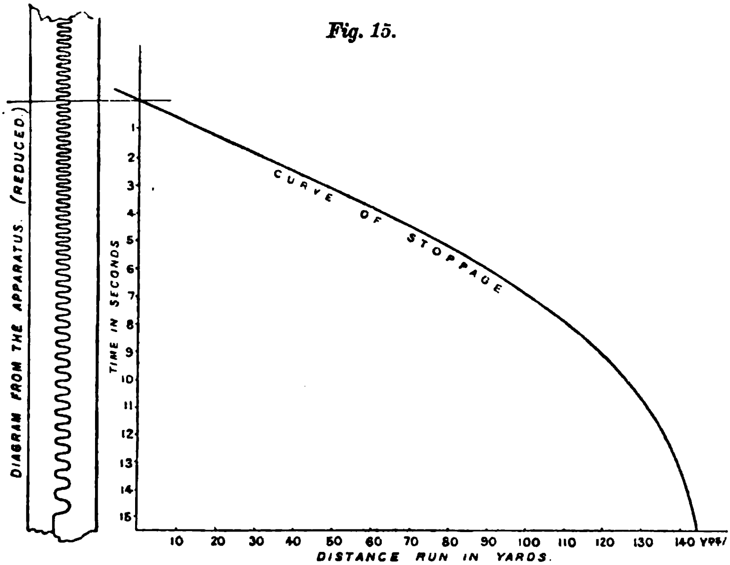


PLAN

made that could be actuated by the leading wheels of the locomotive to eliminate divers questions as to time, and so on. That construction was adopted in the machine he now brought before them (*Figs. 13, 14*). The knife-grinding arrangement on which

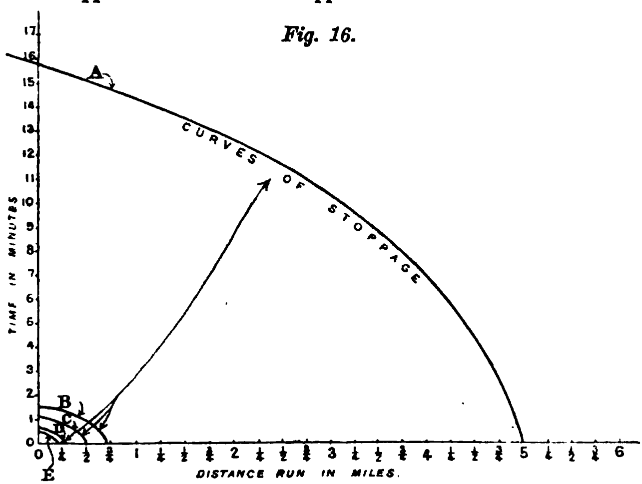
Sir Frederick Bramwell.

Fig. 15.



NOTE.—The distance was measured in yards from the moment at which the brakes were applied or directed to be applied.

Fig. 16.



REFERENCE TO CURVES.

(A) Steam shut off, brakes not applied.
(B) " " hand-brakes only applied.
(C) " " steam- " " "
(D) " " continuous brakes only applied.
(E) " " all brakes applied.

NOTE.—The speed of the train on all occasions was 50 miles per hour when the steam was shut off.

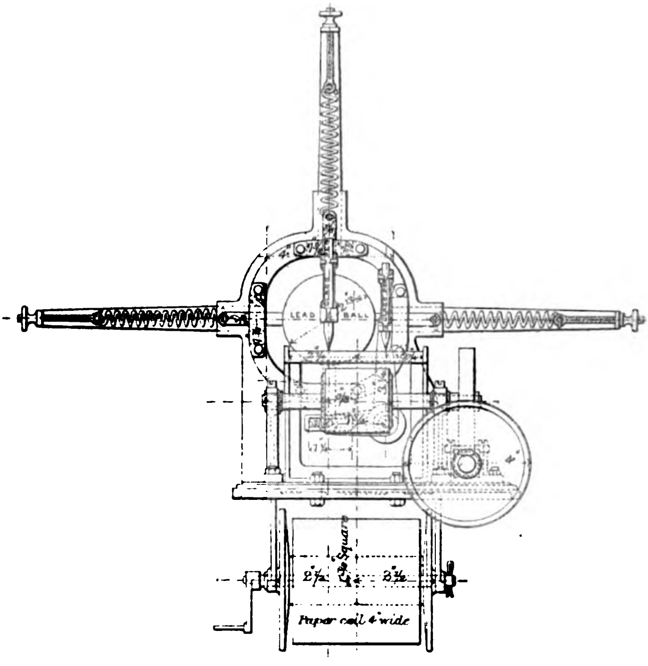
Sir Frederick Bramwell. it was mounted was really not part of the apparatus, but was simply a means to illustrate its behaviour when in use. By working the treadle so as to put the fly-wheel of that apparatus into motion a certain number of revolutions per minute were obtained, and the letting those revolutions die out, caused the pencil to make the same kind of diagram as was made when a train was gradually brought to rest by the action of the brakes. He had placed on the wall an enlarged diagram taken from the instrument, *Figs. 15, 16.* The paper was travelling at a uniform rate in the direction of its length; the transverse movements were made one for every revolution of the leading wheel, and a black line near the top showed the point at which it was directed that the brake should be applied. Before that line was reached the reciprocations of the transverse working-pencil were at a certain rate, so that a certain number of them were made in a second depending on the speed of the train immediately before the brakes were applied. All they had to do, knowing the circumference of the leading wheel, was to count those reciprocations and compare them with the time, as given by the paper travelling at a uniform pace, thereby ascertaining with absolute certainty the speed at which the locomotive was running at the time the brakes were ordered to be applied. Looking at those reciprocations on the portion of the paper below the line it would be seen that they became gradually more and more coarse in pitch—that was to say, the engine was travelling more and more slowly, the train being under the action of the brake, until, as seen towards the bottom of the paper, the train having come to rest, the pencil no longer reciprocated, and a mere straight line was drawn. In that way there was obtained a record of the gradual dying out of the speed of the train under the influence of the brake, and also an accurate record of the distance passed over. With those materials it was competent to construct a curve, as would be seen on the diagram. This was made simply by taking the time and the rate of the traverses of the pencil oscillations. There were several curves on the paper (*Fig. 16*) showing the differing times and the varying distances travelled under conditions changing from stoppage without the use of brake-power, through instances of the use of a portion of the brake, to that where all the power was put on. The speed in all cases was 50 miles an hour before an observation was begun. Steam being shut off when no brakes were applied, the train (see curve A, *Fig. 16*) ran 5 miles and 5 yards on a dead level line by the energy stored up in it. Curve B, where the steam was shut off and the hand-brakes only applied, showed that it ran about $\frac{11}{16}$ths of a mile. In curve C the steam-brakes

were applied, and it then ran about half a mile. In curve D the continuous vacuum brakes were applied, and it ran about $\frac{1}{4}$ of a mile; while in curve E the steam, vacuum, and the hand-brakes were all applied, and the comparative distance that the train ran was shown. He was aware that this statement was not strictly germane to the present inquiry, but the apparatus was an instance of a recorder worked off the leading wheel of the locomotive. He would ask Mr. Molecey to be kind enough to turn the "knife-grinder" for a short time, and to cause the fly-wheel to revolve. This would represent the leading wheel of a locomotive in motion, the clockwork at the same time drawing the paper through the rolls. One of the pencils would be seen working, making the transverse stroke, and having got the wheel into rotation if they let the speed die down the pencil would make a vandyke of the gradually coarsening pitch of which he had spoken. There was a second pencil, the object of which was to enable the operator to make a record by means of a cross stroke at any desired moment, say, when the brakes were ordered to be applied, or in passing a particular mile-post or anything of that kind. As he had said, he was not putting this apparatus forward as being at all an anticipation of the kind of automatic recorders which formed the subject of the paper, but a being an instance where there had been a connection with the leading wheel of the engine by means of which it was possible to ascertain the absolute speed of the train at any moment, and also to ascertain the other incidents he had mentioned. About the time when these brake experiments were being made there was an article in some of the scientific papers stating an eminent foreign engineer had proved that the leading wheel of an engine went more quickly than did the engine itself. There was another article by another eminent engineer to show that it went more slowly. He (Sir Frederick Bramwell) took an engine, moved it carefully along the line, measured the distance travelled due to the circumference of the wheel, and having ascertained accurately the circumference and the distance moved along by the engine for one revolution, he repeated the observation at the mile-posts on the line at a speed of 50 miles an hour with the result (by which he was not at all astonished) that the leading wheel was in truth an absolute measure of the speed of the engine at any velocity at which it might run. Sir Frederick Bramwell.

Mr. William Dawson said that a machine such as the one he exhibited was made by the London & North Western Railway Co., five years ago, for the purpose of taking a record of the condition of the permanent way in much the same way as was done by the Mr. Dawson.

Mr. Dawson. Author's instruments. It consisted of a lead sphere (*Figs, 17, 18, 19*) 5 lbs. in weight held in position by three springs, one vertical and two horizontal. Guides were provided so that motion could only take place in a vertical plane. As the carriage jolted the inertia of the sphere prevented it from moving to the same extent, and the relative movement of the two was recorded by pencils moving with the sphere upon paper connected with the framework of the

Fig. 17.



PERMANENT-WAY TELL-TALE.

Scale 2 inches = 1 foot.

machine. The pencil which registered the horizontal movement worked easily in a vertical socket attached to the sphere itself so as to be independent of the vertical motions, which were recorded by the second pencil, the connection with the sphere being made by a bell-crank which transformed the movement to a horizontal one; consequently lines were drawn on the paper both by the vertical and the horizontal motion of the carriages (*Fig. 20*, p. 94). The paper was drawn forward at the rate of $8\frac{1}{2}$ inches for every mile the train ran by an arrangement of cords and pulleys connected with

Mr. Dawson.

the axle of the carriage, and consequently the diagram was the same if the train was going 10 miles an hour as if it was going 50 miles. On one side of the machine was an electro-magnet connected with a clock in such a manner that contact was made once a minute, causing an oblong notch to be made in the line marked by a third pencil. This electro-magnet could also be actuated by pressing a button, and in this way the quarter-miles and miles were registered by one, two, three or four marks made as the posts were passed, so that the speed of the train could be at once known. When passing a station, the "push" might be worked five or six times, and the name of the place written on the side of the paper. Several diagrams were made over the same piece of road on the same day and showed the accuracy of the machine, almost appearing as if they had been traced from one another.

Fig. 18.

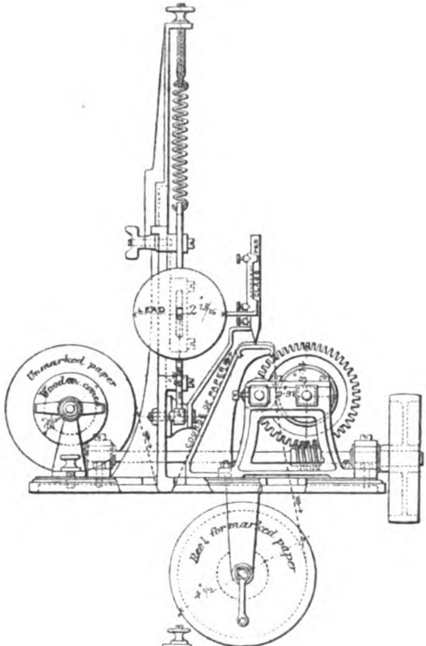
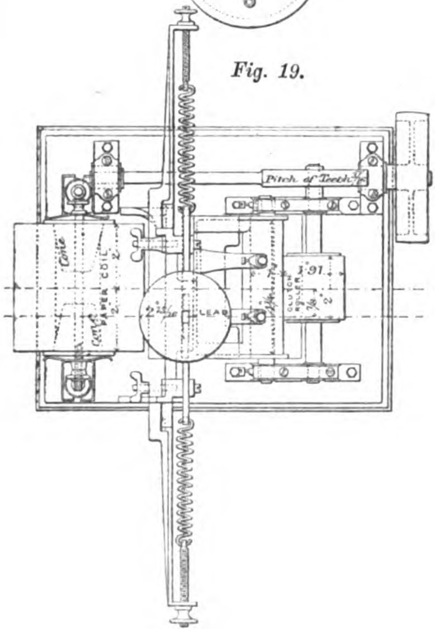


Fig. 19.

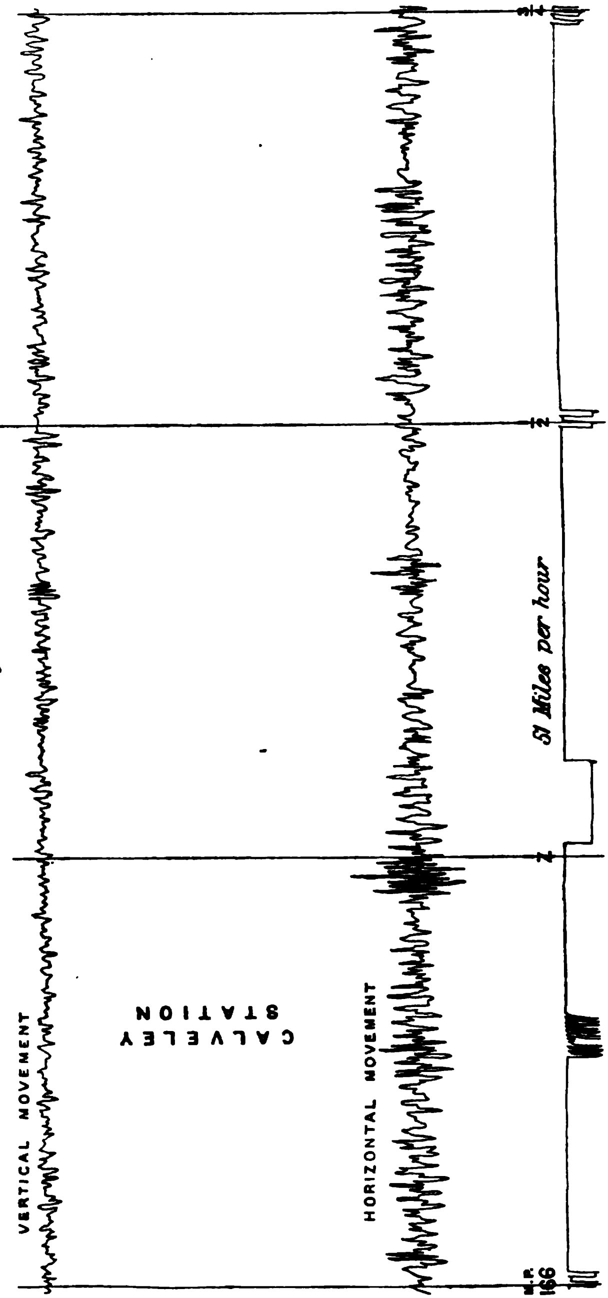


Sir John Coode.

Sir JOHN COODE, President, said a little further explanation was required. Mr. Dawson had said that the diagram was the same

Sir John Coode.

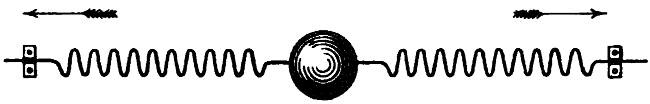
Fig. 20.



whether the train was travelling at 5 miles an hour or at 50. In what respect was it the same? Sir John Coode.

Mr. Dawson: Only as regarded the distance between the horizontal vibrations. One defect of ordinary machines, where the paper was drawn out by clockwork at a uniform rate, was that the horizontal disturbance as indicated by the movement of the pencils varied with the speed of the train. The faster a train travelled the greater was the vibration of the sphere, and consequently if the speed of the train was not known it might be thought that one part of the road was in worse order than another, when in reality the difference was caused by one diagram having been taken at, say 50 miles, and the other at 5 miles an hour. He had suggested, and in fact shown in the drawing exhibited, that a Watt's governor driven by the wheels of the train might be connected with the springs in such a manner as to pull them farther apart as the speed of the train increased, thus giving increased resistance to the motion of the sphere (*Fig. 21*). In this Mr. Dawson.

Fig. 21.

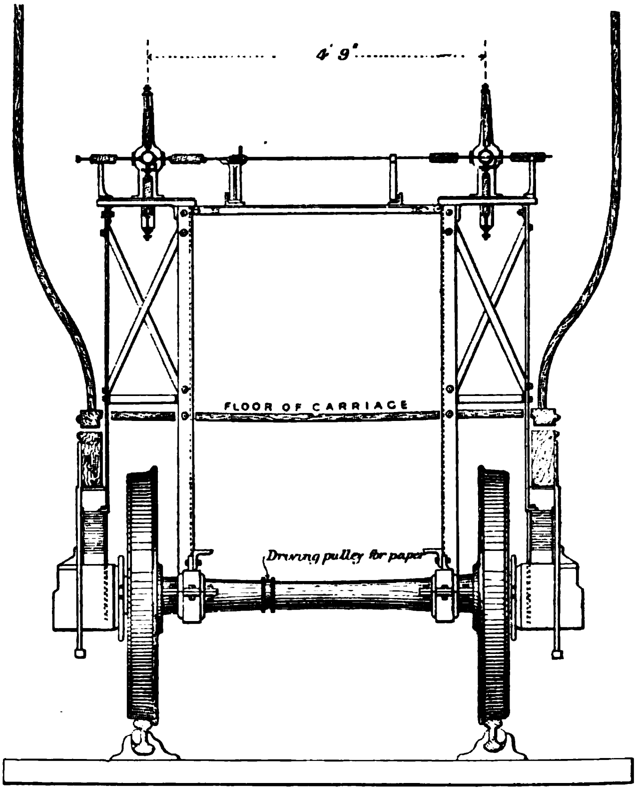


way the range of the lateral movement of the pencil could be made independent of the speed at which the train was travelling. One great defect in all the machines was that they were fixed to the floor of the carriage, and had to encounter the uncertain movements of the springs, as well as the varied motions of the framework in different classes of vehicles, such as four-wheel, six-wheel or eight-wheel coaches. It had been suggested by Mr. Footner, M. Inst. C.E., and partly carried out at Crewe, that they should fix the machine directly to the axle of the carriage in the manner shown in *Fig. 22*, p. 96, and so avoid the sources of irregularities complained of. Another important thing was that if the diagrams were to be of any use at all for indicating defects in the road, they must show each rail separately, because one joint might be down and the opposite one not, and this could be done by having a separate machine fixed over each wheel on one of the axles.

As a matter of practice, however, these diagrams were not found to be of much use. Each portion of the line was examined morning and night by the gangers, who were responsible for a length of

Mr. Dawson. $1\frac{1}{2}$ to $2\frac{1}{2}$ miles, and they and their staff immediately repaired any defect, and were continually advising the District Inspector of the general condition of the portion under their charge; the District Inspector on the other hand was kept constantly employed in supervising the work done by the platelayers, and in calling

Fig. 22.



Proposed Permanent-Way Recording Apparatus.

Scale $\frac{3}{8}$ inch = 1 foot.

attention of the gangers to any defect that they might not have attended to, and the District Inspector was under a Chief Inspector, whose principal duty it was to make periodical inspections from the foot-plate of the whole of the lines under his charge. His

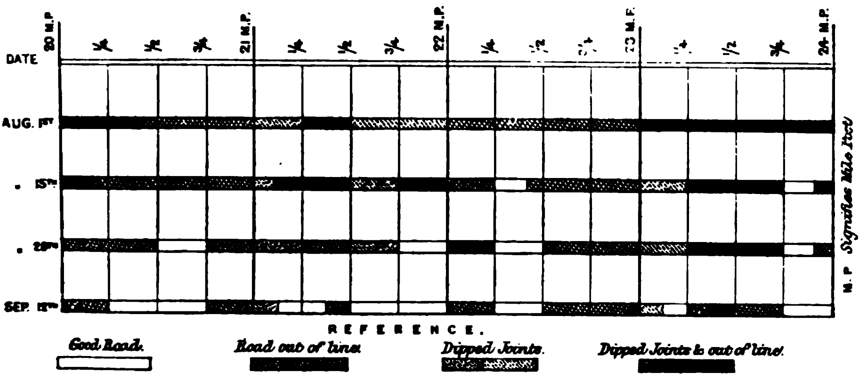
report included the condition of each portion of the road in the following form— Mr. Dawson.

Line. Date of Inspection,

From		To		Condition of Road.
Miles.	Yards.	Miles.	Yards.	

which was afterwards plotted as shown (*Fig. 23*).

Fig. 23.



The London and North Western Railway Co. had taken a large number of records, but it took more time to attend to the instrument and inspect the diagrams than they were worth. They showed miles of road that the engineers did not want to see. Yards of paper were drawn out over lines that were most likely in very good order, but they wanted information about bad roads. Although they had used the machine for some months when it was first brought out, they had not used it during the last four years until last week.

Mr. Dawson. He did not think that any machine would ever supersede or even lessen the necessity of inspection by competent men. A personal inspection not only discovered the defects, but as a rule traced the causes of them, such as "dipped joint," "worn crossing," "rail out of line," "junction," "want of surface drainage," "decayed sleepers," "spent ballast," "loose fishplates," "sleepers insufficiently packed," and so on. The results did not seem very satisfactory so far as they had gone, and the instrument was looked upon as more of a toy than of practical use.

Mr. Kapteyn. Mr. A. Kapteyn said the subject was one which had engaged the attention of engineers for many years. The Paper might be divided into three parts; the registering apparatus, the diagrams, and the interpretation of the diagrams. With regard to the first, the Authors would have greatly enhanced the value of their Paper if they had dealt more fully with the apparatus used by others during the many years in which this problem had been studied. He would refer to one or two instruments which closely resembled what the Authors had produced. In the "Annales des Mines" in 1885 there appeared in the November and December numbers a paper under the title of "Application de la Méthode rationelle aux études Dynamo-metriques," by Mr. Desdouits, one of the chief engineers of the French State Railway. Mr. Desdouits, who had been experimenting for some years on this subject, commenced by employing a single pendulum to which a pencil was attached, and he found, as the Authors had no doubt observed, that under certain conditions of the road oscillations were set up which falsified the diagrams to a great extent. Mr. Desdouits' first idea was to couple together two pendulums, one with the ball below, in the ordinary way, and the other inverted with the ball above, the two being coupled together by a link. The Authors had done a similar thing in putting two pendulums exactly above each other. Of course there was no difference in principle between the two. For practical purposes Mr. Desdouits preferred another form of apparatus—which he would call a differential pendulum—consisting of a heavy disk, or part of a disk rolling over a horizontal surface, and furnished with a movable weight, by which the centre of gravity of the whole could be made to coincide with the centre of the figure, when the whole would be in a state of indifferent equilibrium, so that it could be jerked or shaken into any position. The great defect in this apparatus, as also in that shown by the Authors, was that in experiments of this kind, it was absolutely necessary that when the normal movement or the normal condi-

tions were attained, the pencil should rapidly and automatically be brought back to zero. An engine when running jerked to the right and the left, and in order to investigate the extent of those jerks and their duration the diagram ought to show distinctly a zero line to separate the two kinds of movements. He noticed in the Authors' diagrams there was no zero line. He observed that in Fig. 1 the Authors had provided a spring D in order to bring the pencil back; but in the other recorders he found no similar provision. Two and a half years ago he witnessed some brake trials on the French State Railway with a train of fifty carriages, fitted with the Westinghouse brake. In the last vehicle of that train sundry diagram apparatus and recorders were put, and amongst others, Mr. Desdouits had his rolling disk, or *pendule dynamometrique*, as he called it. It was particularly noticed that in certain jerks of the vehicle the disk acquired a swinging motion like that of a pendulum, imparting to the pencil very undisciplined movements which falsified the diagrams to such an extent that Mr. Kapteyn considered them useless for measuring the retardation and acceleration of the train. He (Mr. Kapteyn) had also in the van some apparatus for investigating different problems connected with the question of continuous brakes; but as they did not bear immediately upon the point before the meeting, he would not at present refer to them further. The instrument was on the table. But to complete that apparatus he wished to add an instrument to measure the retardation of the train, and the shocks, if any were produced. He thought he could improve upon Mr. Desdouits' plan, and constructed the apparatus shown in *Figs. 24, 25, 26*, p. 100. He had called it the retardation-meter because he was principally interested in the methods of retarding a train. The body of the apparatus and its base E were fastened to a solid table fixed to the floor of the experimental van. The lever B was suspended from the point C, and at its bottom carried a weight A. Near C would be seen the point G, where the lever bore against the stem of the piston P, and this piston was attached to a diaphragm which closed a chamber N, filled with water or any other suitable fluid. The piston P also bore against the stem of a small inlet valve O, which cut off a supply of water under high pressure from the tube D, and prevented it from entering the chamber N. On the left-hand side of the lever a similar apparatus was placed for taking records when the train was moving in the other direction. Supposing the train to be moving to the right, and the brakes were applied or retardation caused in any other way, then the acquired momentum of the weight

Mr. Kapteyn.

Mr. Kapteyn. A would push the lever B against the piston P, which in its turn would open the small inlet-valve O. Water under high pressure would immediately be admitted to the chamber N, until the

Fig. 24.

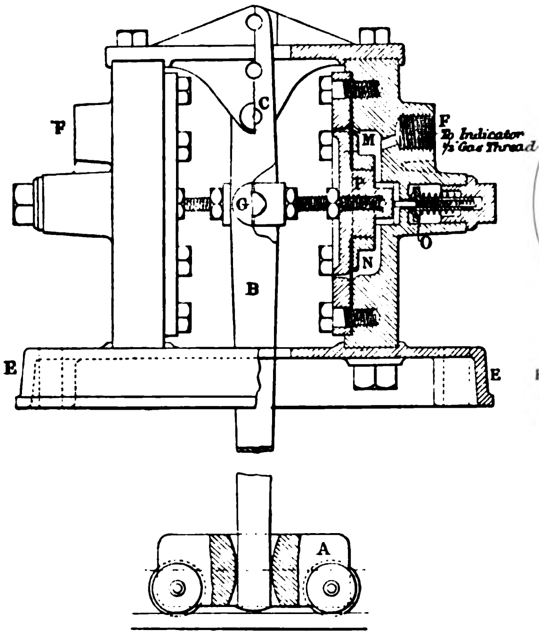


Fig. 25.

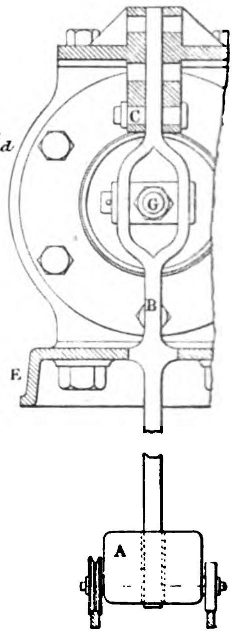
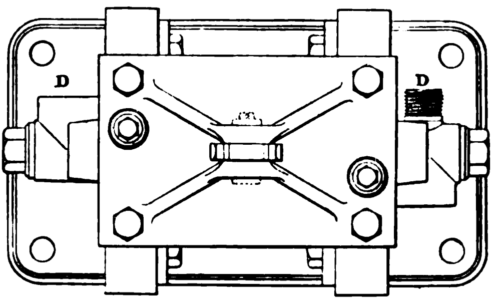


Fig. 26.



RETARDATION-METER.

diaphragm M was in equilibrium between the pressure exerted by the lever B, and the water on the other side of it. The pressure in the chamber N was therefore a direct measure of the retardation

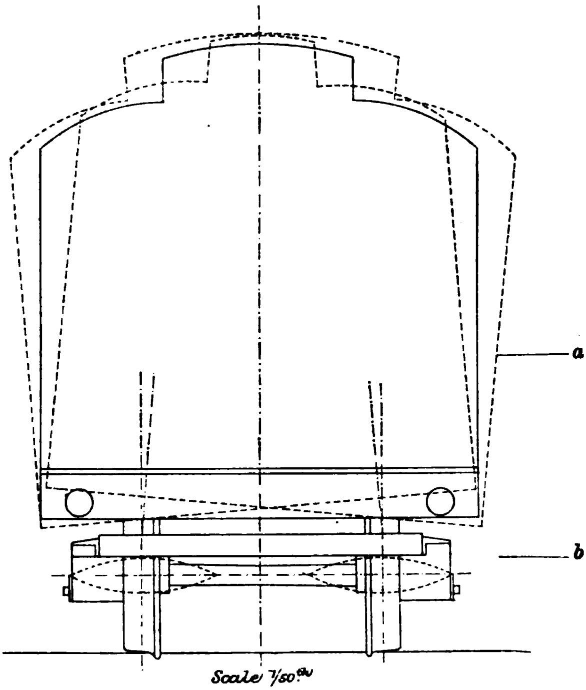
of the vehicle. The apparatus was coupled at the point F to one of the indicators of the instrument exhibited. This indicator was fitted as usual with a piston and pencil, which traced a continuous diagram on a strip of paper moved either by clockwork, or by the train in motion, so as to produce a record of the retardation of the train. The apparatus was used for the first time in May last, in some further brake-trials on the French State Railway, and the undisciplined excursions of the pencil were certainly much less. His idea was that if he could constrain the weight A so that it would be unable to make large excursions, the pendulum action would also be greatly reduced. The results obtained, although they showed considerable improvement, were not to his satisfaction, and he attributed that to three causes. In the first place, difficulties experienced on account of the air contained in the water, but by several times opening a vent-plug and compressing the water, it was possible to get rid of this air, and, therefore, he would say nothing further about it. The second cause was, that the lever B was made very light and elastic, and bent back when a considerable retardation occurred, thus producing vibrations which otherwise they would not have had. In the third place the excursions of the weight A were sufficient to make the action of gravity palpable, and this also caused oscillations which they wanted to avoid. He had now decided to modify the apparatus by making the lever B much stronger and more rigid, and by extending its top, so as to bring the centre of gravity exactly at the point of suspension C; otherwise the lever itself would constitute a pendulum, and give rise to the difficulties which he desired to avoid. The weight A he detached entirely from the lever and made a carriage of it, with a hole through its centre in which the end of the lever worked. The carriage A was placed on horizontal rails fixed on the floor of the van, thus avoiding any tendency for the weight, when once disturbed from its normal position, to fall back, as in the case of a pendulum. It might appear that through these alterations the apparatus also had come into a state of indifferent equilibrium, which he criticised in Mr. Desdouits' apparatus, and in that of the Authors, but really that was not so. The weight A opened through its pressure the valve O, and a certain quantity of water entered the chamber N, and was registered on the indicator. Supposing the retardation to cease, the weight would stop pressing the lever, and the valve O would close. There might be some pressure left in the chamber, but the piston of the indicator was always more or less leaky, and its leakiness could be in- Mr. Kapteyn.

Mr. Kapteyn. creased to any extent. Immediately one or two drops of water had leaked through the piston, the pencil would fall to zero, because there would be no more pressure upon it. In regard to the use of the apparatus on gradients, he would point out that brake-experiments were generally made on known gradients, which therefore could easily be allowed for by raising or lowering the zero-line of the diagrams. He thought the Authors had not paid sufficient attention to this question of the return of the pencil to zero. In all the experiments he had made this seemed to be a most essential point. An examination of the diagrams exhibited by the Authors would show that in several instances the pencil appeared to have remained for some time at a considerable distance from the median line, and this seemed to bear out his contention. Furthermore, he thought the Authors should have given a greater speed to the paper, because all the lines of the diagram were blotted together, and it was really very difficult to see what actually happened. He would not go into the question of the interpretation of the diagrams which the Authors had given, because it required a close examination of all the elements involved and a great deal more study than he had an opportunity of giving to the Paper. The whole matter depended upon the object the Authors had in view. If their desire was to produce an instrument for daily use in which it was sufficient to have an approximate idea of what was going on, he thought they might be considered to have partly succeeded; but in that case, perhaps, a ride on an engine would be equally useful. If, however, the Authors had intended to devise a means of correctly investigating what really happened, then, in his opinion, their instruments were not sufficient.

Mr. Aldridge. Mr. J. G. W. Aldridge said the Authors had stated that carriages might be tested in the same manner as locomotives. It was a matter of common knowledge that so long as the speed was low there was comparatively little oscillation, but by looking along a train of carriages, more particularly Pullman cars, travelling at the rate of 40 miles an hour or more, it might be seen that the oscillations were not only much larger, but that they took the form of a continuous rolling curve throughout the entire length of the train. Another strange fact was that if they could measure the relative position of the two ends of one of these cars, which were over 40 feet long, they would find that the curve was formed not only by the motion of the carriages with respect to each other, but also by oscillations between the two ends of each individual car. This was scarcely noticeable except by measurement, but he

had found from observation that the two ends of the car were out of alignment, as it were, and therefore the whole train from one end to the other, excepting the engine, was forming one continuous and almost regular curve. When the train started these motions were not observed, but as the speed got up, on what old railway engineers knew as "crooks" and "slacks" on the line, in the first place the carriage, especially if it were a light bogie-car, would fall slightly, first on one side, and then on the Mr. Aldridge.

Fig. 27.



NOTE.—The line *a* shows the position of the centre of gravity of the body of the car, and *b* that of the bogie.

other; each drop giving a swing to the upper body, which in most cars weighed not less than 20 tons; so that gradually, owing to what Mr. Pullman had happily termed the accidents and the incidents of the line, the peculiar motion which he had described was set up, and as the speed becomes greater, it resulted in a complete rolling oscillation. By referring to the drawing of the cross section of a car (*Fig. 27*) it would be seen that the plane of least motion was on the axle. Of course even there

Mr. Aldridge. there would be small vibrations—the minute rattlings as it were of the axle—but up to the present these had not accurately been measured: whether Professor Milne's instrument could do so remained to be seen. At the roof of the car, however, they got a considerable motion. He had the pleasure a short time ago of accompanying Mr. Bracebridge Mills when testing one of the Authors' recorders. At first it was placed on the floor of the car, and being capable of recording a movement of 1½ inch it worked in a satisfactory manner. But when, immediately after, it was fixed as close as possible under the roof, the amplitude of the oscillations was altogether beyond the range of the instrument, the pointer going over with a jerk from one side to the other continually, showing that the leverage was considerable and the motion great. He placed these diagrams on the table (*Figs. 28* and *29*). Such oscillations, as long as they were regular, were not altogether hurtful to rolling stock, but he thought railway men would agree that the greatest damage was done when the car suddenly took a curve; when there was a distinct thud, which most travellers had felt. If each car were of the same dimensions and always travelled at the same speed over a given curve with an exactly suitable super-elevation of the outer rail, there would probably be very little oscillation, because all these forces would counterbalance each other; but as it was, cars of varying weight, size, and speed, went over different curves, and as the forces did not agree they got these disastrous motions. Not long ago he saw a new car, which had been used only a few days, with the body partly torn away from the lower frame, and some of the bolts stripped. The whole of the frame had to be renewed before that carriage could go out again. The superintendent ascribed the result almost entirely to the excessive curves over which it was continually passing. In order to obviate this as much as possible, the Pullman Company and the Sleeping Car Company on the Continent were endeavouring to dispense with the upper berths, because when these were occupied at night, they constituted a great weight high above the centre of gravity of the car. This weight increased the swaying, and he believed that these berths were fast being taken down, or used as little as possible, so as to avoid the excessive oscillation at the upper part of the car. The adoption of gas or electricity was also an advantage to the rolling-stock, as the car-builders had had to put their apparatus for generating and storing the power underneath the car. In the case of gas they got about 5000 lbs. dead weight under the floor, and a little less with a storage battery. This brought down the centre of gravity somewhat, and he had

Mr. Aldridge.

Fig. 28.

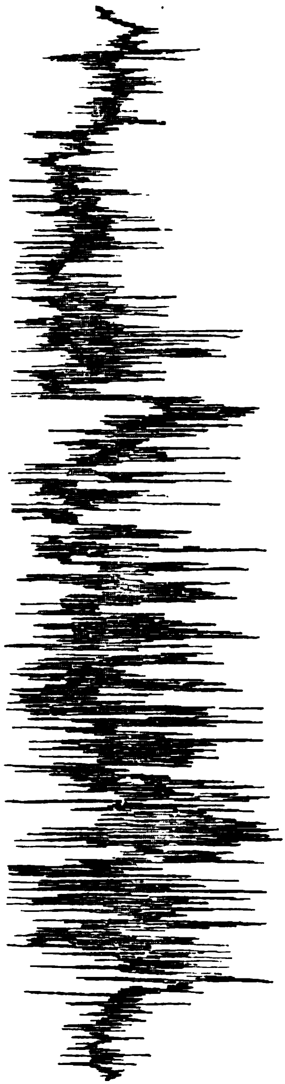


Diagram taken near the Roof of the Carriage.

Fig. 29.

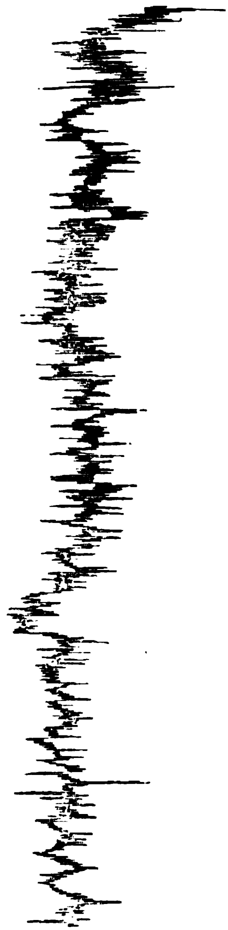


Diagram taken on the Floor of the Carriage.

Mr. Aldridge. been told that it conduced to better running. Referring again to *Fig. 27*, which he had prepared from actual observation, it would be seen that the centre of oscillation was continually changed from one side to the other; at one time it would be found on the plate springs at one side, but as the car went over it would change to the other side, so that it seldom coincided exactly with the centre of the car. That was one reason why there was greater leverage and more disastrous effects with these oscillations. As far as he could learn, one cause of the evil was the use on the side of the bogie of the plate-springs so well known to carriage builders, and he believed in one of Mr. Pullman's latest cars, he had entirely discarded the plate-springs and employed only cylindrical coil-springs. On the Midland he was told they had two cars which had been running some time with such springs; and, moreover, with six wheels to each bogie. These were said to have done the best running of any cars, and to have given no trouble, and it was evidently a step in the right direction. The friction, and consequently the wear and tear, might be greater, but he thought this arrangement overcame most of the jerks incidental to the line. With regard to the best means of measuring these oscillations an apparatus was required with double the range of the one he had seen used, and it was desirable not only to record the movements of the car but the time and the distance travelled as well. For this purpose, the time record and the speed record should be electrically connected, so that on depressing a contact key the two readings should commence and also finish simultaneously. This was necessary in order to get reliable information, because a car that ran capitally at 40 miles an hour might run very badly indeed at 60 miles an hour. In order to test cars properly there should be a sort of measured mile of level track in perfect order, because otherwise the car might be blamed when the fault was in the road-bed. At present the uncertainty in car-building seemed very great; he had seen two cars in which the only apparent difference was in the temper of the springs, and yet in their behaviour they were very unlike, showing that even minor details should be considered. Up to the present the builders had no real guide beyond their own experience, but he thought that this apparatus, for which he supposed they were primarily indebted to Professor Milne, would give the car-builder what the indicator had given to the marine engineer long ago, namely, a diagram by which he could see and ascertain all the varying forces which act during the running of a car, and thereby enable him to attain uniformity of results which now were to a large extent dependent on chance.

Mr. W. W. Beaumont inquired the length and weight of the upper car that was described as pushing itself off the under frame. Mr. Beaumont.

Mr. Aldridge said the weight of the upper car would be about 16 tons, and the two bogies 5 tons each. The new bogies that were very likely to come into use were made with Fox's compressed steel frames, and were much lighter altogether; but the present bogies could not be put down at less than 5 tons each. The length of the upper car was 42 feet. So far as he knew there was nothing novel in the connection between the body and under frame of the car, excepting that the side frames were filled in with wood; they had considered the accident to be due simply to the bad road. Mr. Aldridge.

Mr. W. W. Beaumont said a great many serious accidents happened in the United States with the very long and heavy cars there used. Although he had no practical experience of them, he often examined the statistics of these accidents, and was led to suspect that some of them must be the result of the enormous weight and length of the cars. The inertia of this heavy load had a great deal to do with the derailments which formed so large a proportion of the whole of the accidents in the States. Of the total number of accidents that occurred, derailments constituted something like 33 per cent., and of these about 52 per cent. arose from unexplained causes. He thought that the fact that this carriage body had by its inertia pushed itself off the lower frame might throw some light upon this matter. Possibly it was because it was very heavy, as it did not appear to happen with shorter and lighter carriages running on the same lines. Mr. Beaumont.

Mr. F. Bracebridge Mills in reply for the Authors said, that in his opening remarks he had referred to a diagram he had taken on the 30th of November last year, on a journey from Cannon Street to Sevenoaks in one train, and from Sevenoaks to Hastings in a second train, and he had called attention to the fact that the diagram showed the fore-and-aft motion to be much greater between London and Sevenoaks than between Sevenoaks and Hastings. This he had suggested was due to a difference in the balancing of the locomotives employed to draw the two trains. Mr. Shelford had suggested that the change in the diagram was not due to a difference in the balancing of the two locomotives, but to the fact of Sevenoaks being about the summit of the line, and had further said that if Mr. Mills had taken a diagram on the return journey, he should expect to find the nature of the diagram reversed. Mr. Mills had referred to those diagrams he possessed of the Hastings line, but did not find that Mr. Shelford's expectations were realized. With Mr. Mills.

Mr. Mills. a view of arriving at some satisfactory conclusion on that point, he had made it his business to take another journey to Hastings and back, and he had brought with him the diagrams obtained. He had had the benefit of the valuable assistance of Professor Perry in making the tests. It would be seen from the diagram that on the down journey the average range of motion between Cannon Street and New Cross was 1 millimetre, from New Cross to the mouth of the tunnel between Chislehurst and Dunton Green 1½ millimetre, being greatest just after passing Chislehurst where the road appeared to be level, namely, 2 millimetres. It appeared that the down grade commenced just before Sevenoaks, as shown by the instrument and his observations; and from that point to Tunbridge Wells the diagram averaged 1½ millimetre, not being so wide at any point as on the straight run through Chislehurst. From Tunbridge Wells to about half way to Wadhurst the diagram showed a slight rising gradient, where the motion recorded was less than 1 millimetre. From Wadhurst to a point a few minutes before passing Battle the diagram was larger than on any other part of the line, averaging 3 millimetres, and measuring in some places as much as 5 millimetres. From Battle and St. Leonard's to Hastings the range of motion fell to about 1 millimetre. On the return journey there was nothing to call for special notice until Battle was passed, where the fore-and-aft motion perceptibly increased, measuring in places between Battle and Etchingham as much as 5 millimetres. It would be observed that the diagram was the same on the down as the up journey, the greatest motion occurring at the same point on the line. From Etchingham to Tunbridge Junction the average motion was 1½ millimetre, and from Tunbridge Junction to Sevenoaks it was the smallest recorded during the whole journey, the diagram between those stations being everywhere less than 1 millimetre in width. After passing Sevenoaks there was a slight increase in the range of oscillation, and a few minutes before reaching Chislehurst the diagram expanded to about 3 millimetres at a part where the road was apparently level. About the same range of motion was recorded at that point on the down journey. From Chislehurst the average was about 1 millimetre, which, however, increased to about 2½ millimetres when running through New Cross. In measuring the diagrams he had, of course, been careful not to take in account the effect produced by the application of brakes, or by the train being suddenly started from rest, or the speed suddenly increased or retarded. He did not. however, think that the experiment could be taken as conclusive; he was not himself satisfied with it. The

only way of arriving at a satisfactory conclusion would be to take diagrams on the two engines to which he had referred, when running under exactly similar conditions; that was, if they could possibly be identified. The diagrams were before the members, and would speak for themselves. He believed that the instruments recorded the fore-and-aft motion with perfect accuracy. With regard to Mr. Kapteyn's apparatus, he confessed that he was unable to follow closely the explanation given of it. It appeared to be rather complicated, aiming at a good deal more than had been laid down in the Paper. There was one point to which Mr. Kapteyn had drawn attention, namely, that in Fig. 1 there was a spring D shown which drew the weight W back to its position of rest, and he seemed to think that that was not shown in any other instruments. Mr. Mills would like to call attention to *Figs. 7, 8, 9.* It would be seen that there was a view of the beam and weight in a deflected position, and there were compensating springs shown. Mr. Kapteyn had laid great stress upon the point of returning the pencils to zero line, and seemed to suggest that in the Milne-McDonald diagrams, the serpentine appearance indicated faulty recording because the pencil remained in a deflected position when it should have returned to zero. That was not the case; the zero line was always the centre of the diagram of normal motion at any place, the serpentine appearance being caused by the inclination of the carriage when on curves or gradients. Mr. Mills thought that the action of gravity in tending to make the pencil set itself in a true vertical position appeared to indicate a probable defect in Mr. Kapteyn's apparatus. So far as he had been able to follow the description of Mr. Kapteyn's retardation-meter, he understood that by the inertia of a weight attached to the end of a long lever which operated certain valves so as to admit water under varying pressure to ordinary piston indicators, a record of the retardation or acceleration of a train was made by the pencils of these indicators on a continuous strip of paper. If the coach containing Mr. Kapteyn's instrument were running on a steep gradient, or round a curve, the diagram would, he thought, be a very unreliable record of the retarding effect of the brakes. Suppose the coach to be running down a decline, the weight at the end of the lever would tend to move forward, and acquire a vertical position by the force of gravity, causing the lever to bear against the valves and so increase the pressure of the water behind the pistons of the indicators; thus a diagram representing a retardation of the train would be produced, whereas in all probability

Mr. Mills.

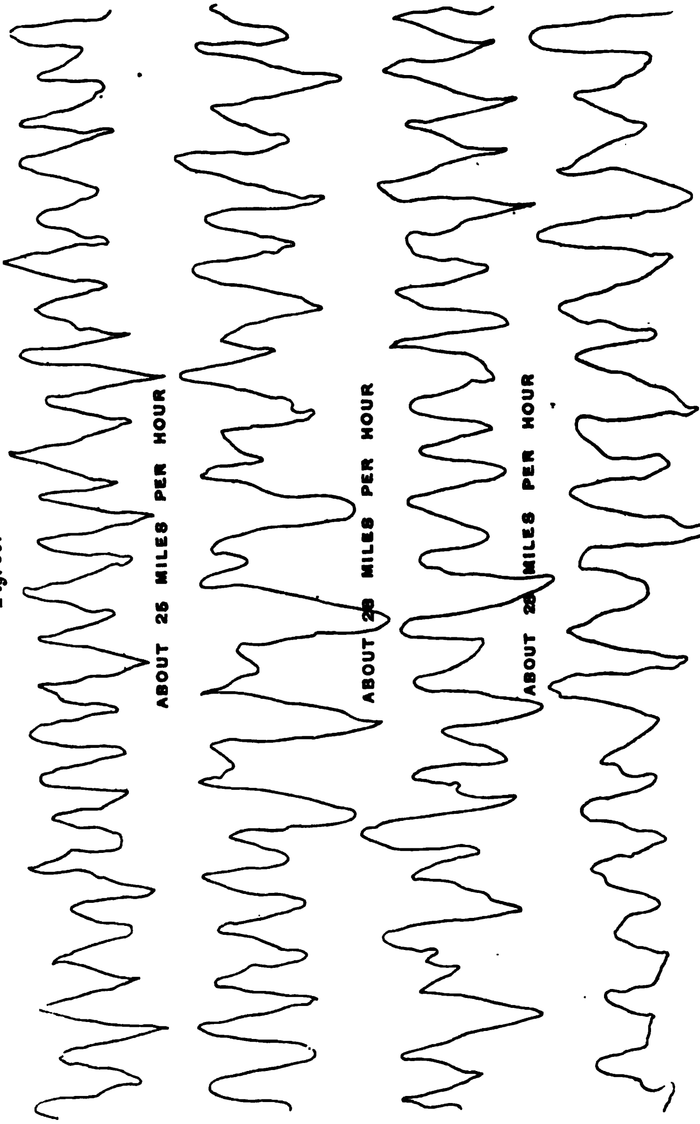
Mr. Mills. under such circumstances the speed of the train would have been accelerated. If Mr. Kapteyn would examine the original diagrams produced by the Milne-McDonald instruments, he would find that in many cases, according to the purpose for which they were taken, the speed of the paper had been such that every movement of the pencil could be traced. Mr. Kapteyn had evidently drawn his conclusions from the exaggerated diagram on the wall, which was really only an outline representation of the original. Mr. Moir had called attention to a peculiarity in the diagrams which he had himself inadvertently omitted to mention, but which had been referred to by the Authors, namely, that they gave a record of when the brakes were applied. That was, indeed, one of the most interesting features of the diagram of fore-and-aft motion when taken in an ordinary carriage, and by referring to the Hastings diagrams it would be seen quite distinctly where the brakes had been applied suddenly or gradually. The instrument would record the retardation of a train by the careful application of the brakes before it could be noticed by an ordinary passenger. Reference had been made as to the best position in which to place the apparatus in the train, and the President had expressed an opinion that the position in the coach itself might also be a matter of importance. Those were points which were decided by the nature of the particular experiment, and the purpose for which it was being conducted: whether for testing a coach, a locomotive, or the permanent way. For testing the running of a coach it was necessary, as had been pointed out by Mr. Aldridge, to take it over the same track many times at varying speeds, and with the instrument in different parts of the coach; or preferably with three or four instruments fixed in different positions and recording simultaneously. Similarly with locomotives being tested for balancing; an instrument for recording fore-and-aft motion, such as was represented by *Figs. 11* and *12*, was stood on the foot-plate, and the engine run backwards and forwards over a level track at different speeds, both with steam on and steam off. For testing tracks he had always endeavoured to place his instruments as near as possible directly over one of the axles, or in the case of bogie cars, directly over the foremost bogie. They could of course be fixed in front of the buffer-beam of the locomotive, as had been suggested by Mr. Hill, so as to get the motion of the leading wheels, but he was not aware that that had ever been done. When designing instruments especially for car-testing, he would not fail to consider the valuable suggestions made by Mr. Aldridge.

Mr. Mills.

It had been suggested by Mr. Dawson that one of the greatest defects in all such instruments for recording irregularities in the permanent way, was that, being fixed to the floor of the coach, the uncertain movements of the springs were experienced. Mr. Mills did not think that any serious error was introduced in this way when the instrument was placed directly over an axle. Mr. Dawson had claimed great accuracy for the instrument he exhibited, constructed by the London and North Western Railway Company, in which the free swing of a heavy ball was constrained by three springs pulling in different directions. Mr. Mills would have thought that the springs of the instrument were as liable to uncertain movements as those of the carriage. It was probably the combined uncertainties of the carriage and instrument springs that had apparently caused Mr. Dawson some trouble. Mr. Mills had noticed that when the ball of the London and North Western Company's instrument was displaced from zero and then released, it occupied an appreciable time in coming to rest. It did not appear so dead beat as the Milne-McDonald vibration-recorder. He admitted that he thought it preferable to eliminate the effect of the springs by taking the motion directly from the axles, but the plan suggested by the London and North Western Railway seemed rather costly to carry out, as it necessitated a specially constructed coach. It had been proposed to apply the Milne-McDonald vibration-recorders for track-testing in a like manner, but in the case of those instruments it was only necessary to fix two of them at the backs of two opposite axle-boxes as shown in the sketch. By such an arrangement all the advantages of the London and North Western Company's instrument would be obtained without the cost and inconvenience of a special instrument-coach. Unfortunately, however, by the nature of this instrument no such ready means of application could be adopted. He did not quite see the point of Mr. Dawson's reasoning when he said that it took more time to attend to such instruments and inspect the diagrams than the records were worth, as they showed miles of road the inspector did not want to see; yards of paper being drawn out over good roads, whereas they only required information respecting bad roads. Mr. Dawson had already told the meeting that gangs of men were despatched to inspect short lengths of the line every night and morning, but Mr. Mills would have thought that the inspection could have been more economically and expeditiously carried out by one man with a recording instrument travelling on a locomotive or carriage, who would thus obtain a record of the condition of say 50 miles of the line in less time

Mr. Mills.

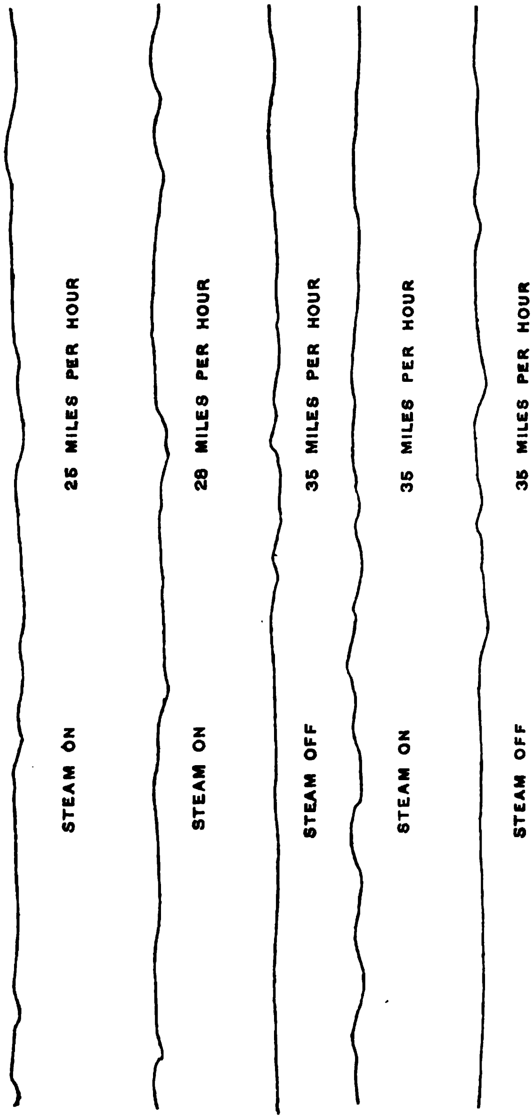
Fig. 30.



Before the Alteration of the Balance-Weights on the Driving-Wheel.

Mr. Mills.

Fig. 31.



After the Alteration of the Balance-Weights of the Driving-Wheels.

Mr. Mills. than would be occupied by several gangs of men walking along the track, not to mention the possibility of the men overlooking faults. He could quite understand that such an instrument as Mr. Dawson had described was inconvenient to use, and that a great deal of time might be occupied in coupling the instrument-car up to the train and preparing for a test, but surely if a defect existed anywhere it was in the particular apparatus or its method of application rather than in the general system of inspection of the permanent way by vibration-recorders such as those described by the Authors and himself. It had been asked if it were possible from the character of the diagrams to ascertain where the fault was due to the engine and where to the permanent way. Faulty balancing of the engine affected mainly the fore-and-aft motion, but irregularities in the permanent way had practically no effect on that portion of the diagram; indeed, the fore-and-aft motion might be taken as produced wholly by the locomotive itself. Faults in the permanent way showed themselves most in the diagram of vertical motion, and when such diagrams were taken in carriages or on locomotives, it was the excrescences upon them which indicated the jerks caused by defects in the line. It was true that each locomotive or carriage had its characteristic oscillation, but that would be repeated throughout the run, only becoming larger as the speed increased. It had also been found that the same line reproduced its characteristic diagram on whatever locomotive or carriage the tests were made; the diagrams only differing in dimensions. The opinion had been expressed that too much was made of the balancing of the engines in this Paper, and it seemed to be suggested that there was no absolute proof that the abnormal fore-and-aft motion that had been experienced, was so much due to defective balancing. He would call attention to *Figs. 30, 31,* representing diagrams taken by the Authors on engine No. 138 of the Imperial Japanese Railway. In the first instance, *Fig. 30* showed the absolute motion of the locomotive when the balancing was known to be faulty; it was abnormally great. After making this experiment Professor Milne and Mr. McDonald had suggested that certain alterations should be made in the balancing; those alterations were carried out, and the engine was again tested, the result being shown in the diagrams in *Fig. 31,* which were obtained under exactly similar conditions. Those tests seemed to prove that the fore-and-aft motion was due in a great measure to differences in balancing, because the same engine working under similar conditions, except as to the adjustment of its balance-weights, produced in the one case a

curve, and in the other almost a straight line. With regard to the difference in the consumption of coal, he thought the Appendix to the Paper clearly showed the opinions expressed by the Authors on that point to be well founded. It had been suggested that it would be better to drive the drums of the instruments from the axle of the carriage or locomotive, in order to more readily locate the faults. Undoubtedly they would get a better idea of the position of any particular disturbance if such a course were adopted; but he had always understood that Professor Milne regarded it as a great feature in his apparatus that it was portable, and capable of being used in any carriage or on any locomotive without special fixing. When once they came to drive the drums from the axle, it was necessary to have a specially constructed carriage, and the nature of the instrument was entirely altered. Mr. Mills.

Correspondence.

Mr. John A. F. Aspinall took exception to the statement of the Authors that the economy of fuel was due to balancing; more probably it was to be ascribed to the mere presence of an inspector or investigator watching the experiments. Perhaps 10 per cent. of the fuel could be saved on any of the best locomotive engines in England, without spending a farthing on additional mechanism, by sending an inspector to travel on the engine for a month. Knowing they were watched, the men would take more care. The wear of tires was affected by so many different things that it was most unwise to deduce any argument from so small a number as the Authors had tried. Mr. Aspinall.

Mr. D. K. Clark could confirm the opinion of the writers of the Paper, that a proper equilibration of the engine was not only conducive to economy of maintenance, but was beneficial also in reducing the resistance on the rails at high speeds, and economising fuel. Mr. Le Chatelier, about forty-one years ago, experimented with an outside-cylinder goods locomotive on the Orleans railway. The engine had originally been unbalanced, and vibrated when running with considerable oscillatory movement. The wheels were afterwards fitted with counterweights so distributed as to effectually extinguish the oscillation. The following average quantities of fuel were consumed during three months, the engine Mr. Clark.

Mr. Clark. being in each case under the charge of the same driver, and doing the same kind of work:—

		Coke per Mile. Lbs.	
1848.	December	49·5	Without counterweights.
1849.	January	50·3	
„	February	42·3	Average of twelve trips, of which ten only were made with counterweights.

This showed an economy of about 8 lbs. of coke per mile, or 15 per cent. Mr. Clark, in 1854, designed some outside-cylinder locomotives for the Great North of Scotland Railway, with a complete system of balancing. They ran at all speeds with perfect steadiness, and he believed that they were the first outside-cylinder engines so fitted in this country. In his Paper on locomotives, read before the Institution in 1856,[1] Mr. Clark gave the results of an experiment in balancing the "Canute" single outside-cylinder express engine, which had previously been fitted with balance-weights of 85 lbs., one to each driving-wheel. These were replaced by a weight of 186 lbs. for each wheel, balancing the whole mass at the crank-pins. The engine ran so much more steadily and freely with this alteration as to take the engine-driver by surprise, for on the first day of trial after the new weights were applied, the train considerably overshot the stopping-stations. The economy of fuel thus effected was at least 10 per cent. This trial was made on the London and South-Western Railway. The effective equilibration of locomotives, whether with inside-cylinders or outside-cylinders, was now thoroughly understood.

Mr. Cowper. Mr. E. A. Cowper said that apparatus of the kind described in the Paper was calculated to assist railway companies and managers in making improvements in the running of engines and carriages. Some years ago he had given a good deal of attention to the subject, and his first idea was to have a fair-sized cannon ball hung in the centre of a square box by a spring above, and a spring below, and four other springs, north, south, east, and west. Then, to prevent extreme and continued oscillations there must be resistances or frictions introduced, say in the form of "cataracts," that would give resistance and no recoil. The motions of the ball were to be communicated by means of levers to pencils, so that one pencil should record the vertical motion, one the side motion, and one the fore-and-aft motion of a carriage. A very good form of apparatus (modified by "cataracts") would be the "seismograph," that he

[1] Minutes of Proceedings Inst. C.E., vol. xvi. p. 18.

submitted to the committee on Earth Tremors at the British Association, though the atmospheric support for the weight, for vertical motion, would hardly be necessary in the case of railway carriages. Of course, in testing a line of railway, the instrument should first be tried several times over a good piece of road, to establish, so to speak, the pattern of vibrations on a good road; then, with the same carriage and instrument, the doubtful road should be run over. And *vice versâ*, in testing engines or carriages, they should be compared with a good sample, and always over the same piece of road, the instrument occupying always a corresponding position in a train. He trusted railway engineers would institute experiments on their lines, in the interests of the public. Mr. Cowper.

Mr. GEORGE HODGKINSON desired to ask if any, and what notice was taken of atmospheric influences likely to bear on the result at the time of the trials and experiments; such as the velocity of the wind, and its direction in relation to the motion of the train, the state of the weather at the time, and whether the diagrams were taken after a long spell of wet, or in fine weather. The fact of being in a cutting or on a bank, although having a certain effect on any one particular diagram, would, with an instrument which would indicate the locality, give comparative results only, both as to the state of the permanent way and the working of the locomotives. A systematic gauging of the wind would assist much in arriving at a satisfactory conclusion, and his mentioning the "Tay Bridge Disaster," would, he thought, give force to his argument. Reference was also made to "swaying" locomotives in the Paper; this also would be greatly affected by the direction and velocity of the wind. Mr. Hodgkinson.

Mr. J. C. PARK thought great credit was due to the Authors for having devised an apparatus so simple and sensitive, and yet so reliable in its action. The instrument would, no doubt, record faithfully all inequalities in the rolling-stock due to imperfections of the springs, as well as any defects in the permanent way. With these diagrams the permanent-way engineer would be able to justify himself when the condition of the road was questioned by other departments. With regard to the unsteady running of locomotives, although the present method of balancing the disturbing forces by calculation and verifying the same by running the engine suspended in slings gave satisfactory results in practice, this instrument would be useful in checking the correctness of the old method of balancing at different speeds. Again, the difficulty in determining the proper strength of springs for carriages of new construction and large carrying capacity would be more readily Mr. Park.

Mr. Park. overcome with the help of the vibration recorder. As to its value for traffic department purposes, he was of opinion that it would only be useful for experiments.

Prof. Perry. Professor PERRY regretted his unavoidable absence from the discussion on his friend's Paper, but he was glad to think that Mr. Bracebridge Mills had added so much valuable matter to the information given by the Authors, and had also been able to answer the inquiries made during the discussion. He thought that the significance of the new departure had been greatly neglected in the discussion. Here was a small instrument which could be carried in any part of a train or placed on any part of a bridge, and it would record with wonderful exactness the actual motion. Hitherto engineers had depended on their illusory sensations, or on records of the relative motions of different parts of a structure, made by most expensive and large contrivances which could not be altered in position. Sir Frederick Bramwell had referred to Mr. Payne's pedometer as an anticipation of the Author's vertical vibrator, and in the same way it might be mentioned that the Author's fore-and-aft and lateral vibrators were pendulums and that pendulums had been used as seismoscopes for many years. This was all quite true, but as Sir Frederick admitted, there was a difference between making a record of a jolt, and recording accurately the motion during a jolt. The instruments exhibited were not mere jolt indicators or counters; in every detail they had been worked out on scientific principles so that there should be packed in a small box one or more recording bodies, whose own vibrational periods should be very slow, so that the pencils would remain nearly at rest whilst the paper moved underneath them with the motions to be recorded. Mr. Dawson had referred to a ball controlled by springs of which he had had experience, and from that experience he seemed rather to doubt the usefulness of Milne's vibration recorder. Professor Perry ventured to question any deductions made from Mr. Dawson's experiments, or from experiments with any apparatus which could set up vibrations of its own. It could not be too well remembered that this instrument was the outcome of fifteen years' expensive experimenting with all kinds of vibrating bodies used in Japan as seismoscopes. An ordinary vibrating body would record a jolt, but the record would be large or small, according to all sorts of chance circumstances. The problem solved by the present instrument was the recording to scale of all the vibratory motions. If engineers were satisfied that this was the case, there could be no question as to its usefulness. The remarks made by Mr. Aldridge and others showed that in modern rail-

way carriages the motions of different parts differed very greatly, Prof. Perry. and surely, to any one accustomed to engineering calculations, it must be evident that a complete knowledge of these motions was absolutely necessary if they were ever to escape from a mere rule-of-thumb method of design. At present they only assumed that they knew the forces to which different parts of carriages were subjected. Any one who looked at these instruments making their records would see that his own sensations were quite unreliable in giving evidence of the motion of the carriage. He was glad to see that Mr. Aldridge welcomed the instrument as a thing indispensable to the carriage builder. As a detail that would have been improved long ago by the use of the instrument, he might mention the springs, which were now made usually of the commonest Bessemer steel, although it was well known that good spring steel was six times better for such a purpose, a cubic inch of spring steel having six times the resilience of the material of which carriage springs were now usually made. Of course the instrument gave different kinds of records when placed in the middle of a Pullman car or at one end; but in either position, the fore-and-aft record showed in very plain writing the balance or want of balance of the engine; and the up and down record showed in equally plain writing the state of the permanent way. In either case the engineer got information about his engine and the permanent way, and if, besides this information, the largeness or smallness of the writing gave him other information more interesting to carriage builders, he would not find this an objection. If, however, he was in doubt, let him keep the instrument always in the same relative position in the carriages. Mr. Moir seemed to doubt the usefulness of the instrument until a specimen could be placed in a guard's van, making a record every journey, the record giving distances as well as times, and no hitches being possible in its working. Although Professor Perry agreed with Mr. Moir that the vibration-recorder might be improved up to such perfection as this, he ventured to think that not only in its present state, but even in the state in which it was two years ago, when he first tested it, the instrument was a useful one, for which there was a demand among engineers, and any engineer who knew his line thoroughly must be delighted to watch the record a-making at his side. A stranger was not astonished to see a great up-and-down motion on a bridge, nor even the great sidelong motion which one was sorry to find recorded on some bridges in London; but he might be astonished to discover on every journey, through a particular cutting, at a

Prof. Perry. particular place, a considerable up-and-down motion. But the engineer of the line knew, or ought to know quite well, what the record indicated. It was his opinion that after a little companionship with one of these machines on his journeys, an engineer would be able to read its writings with very much clearer eyes, and that even in the guard's van, making its locked-up diagram, it would not have a more useful function than it might have had two years ago at the side of the engineer. Furthermore, he did not think that Mr. Moir, or the Authors of the Paper, could tell to what uses such instruments would be put. They recorded actual motions, and therefore in the construction of roofs, bridges, and ships, and all large structures, they would be useful. Of smaller size, they might be of great assistance in the balancing of machinery in general. Until seismographs on similar principles were invented by Professors Ewing and Milne, everybody made the most absurd assumptions as to the motions of the earth and of buildings during an earthquake; whereas now there was certainty on those points. It seemed to him that certainty as to the nature of vibratory motions was more to be desired at the present time by engineers than almost anything else.

Sir William Thomson. Sir William Thomson said that when Mr. Milne was last in England he explained the instrument invented and worked out by himself and Mr. McDonald for registering the three components of oscillation, or of change of motion, of a railway train, and showed it in action on a railway journey from Largs to Glasgow. Sir William Thomson was much interested in it, and in the principles which had been worked out, as it seemed to him, with great ability, and to a result of great practical utility, in this instrument. He believed that even for an ordinary timekeeper on ordinary goods and passenger trains, the instrument would be very valuable in the economy of railway management. For the all-important engineering questions of balancing and other details of the locomotive, and of the condition of the line in respect to the rails, and the stability or elasticity of their supports, and the character of the roadway itself, especially on bridges, the instrument might be found largely useful.

2 December, 1890.

SIR JOHN COODE, K.C.M.G., President, in the Chair.

The following Associate Members have been transferred to the class of

Members.

MARCELIN JOHN CHABREL, B.E.
FRANK GOTTO.
EDWARD HOPKINSON, M.A., D.Sc.
HUGH LEWIN MONK.
JOHN HEMPHILL MORANT.
GEORGE MOYLE.
MATTHEW JAMES JOSEPH PATRICK NORMAN.
HENRY OLIVER.
ERNEST IFILL SHADBOLT.
ERNEST ALFRED SIBOLD.
ALEXANDER SIEMENS.
JOHN SIMMONS.
WILLIAM HARRY STANGER.
CHARLES FROGGATT WIKE.

The following Candidates have been admitted as

Students.

ALFRED SEABOLD ELI ACKERMANN.
EDWARD HAZLEDINE BARBER.
ERNEST ALBERT SEYMOUR BELL, F.C.H.
EDWARD CHARLES BICKERSTETH.
ARTHUR GEORGE BRISTOW.
HENRY CHARLES BRABAZON CAMPBELL.
JOHN FRANCIS CARR.
HARRY GEORGE CHRIST, Wh.Sc.
FRANK CLAYTON, F.C.H.
FREDERICK CHARLES COLYER.
JULES FERDINAND CONRADI.
OSMOND DAWNAY.
STEPHEN MITCHELL DIXON, B.A.
RICHARD FREDERICK DRURY.
NICHOLAS DUNSCOMBE.
BERTRAM WYBURNE ELLIS.
SOMERS HOWE ELLIS.
PAUL TRAUGOTT JULIUS ESTLER.
FRANCIS DOUGLAS FOX, B.A.
GEORGE WILLIAM GAIT.
WILLIAM GILBERT, Wh.Sc.
WILLIAM JOHN GRIFFITHS.
ISIDORE HOFFMANN.
HENRY WILLIAM MACLEAN IVES.
WILLIAM ERIC LEIGH JENKINSON.
PERCY JOHNS.
CHRISTOPHER WATKINS KING.
WILLIAM ARTHUR BAIRD LAING.
RALPH MORGAN LEWIS.
HARRY CALDER LÖBNITZ.
DUGALD MCLELLAN.
ARTHUR WOODROFFE MANTON.
WILLIAM GOSLING MOORE.
ERNEST CHARLES ADAMS MUMME.
GEORGE EDWARD LUTHER POULDEN.
EDWARD HULME RIGBY, B.Sc.
GERVASE HENRY ROBERTS.
KEITH ROBINSON, A.K.C.
LEONARD COWLEY SEAVILL.
JOHN MILES SIMSON.
ERIC ARNOLD SLATER.
WILLIAM GRIMSHAW STONES.

Students—continued.

Hugh Stowell.
Frank William Swift.
Lucas Thomasson.
John Edward Thornycroft.
Richard Fenwick Thorp.
John Henry Tonge.
Stanley Tooth, B.A.
Robert Ponsonby Loftus Townshend, B.A.
Bertram Vallance.
Eric Hamilton Whiteford.
Arthur John Williams.
Benjamin Leonard Wilson.
Norman Forster Wilson.

The following Candidates were balloted for and duly elected as

Members.

Frederick Robert Bagley.
William Evans.
Herbert Septimus Harrington.
Clemens Herschel.
William Rich Hutton.
John James Jones.
William Redfern Kelly.
Morice Leslie.
Hyalmar Frederick Stavelius.
William Thow.

Associate Members.

Joshua Thomas Noble Anderson, B.A., B.E.
Frank James Appleby.
Thomas Arnold.
Samuel Athim.
John Edmund Bach.
George Herbert Bayley.
Raymond John Birt, Stud. Inst. C.E.
Arthur Sackville Boucher.
Thomas Allen Bullough.
Edward Burton, B.A., Stud. Inst. C.E.
Evaristo de Chirico.
Thomas Clarkson, Wh.Sc., Stud. Inst. C.E.
David Decimus Coath.
William Bartholomew Cole, Stud. Inst. C.E.
Henry Paul Ramsay Copeland.
William Wallace Copland.
Arthur Cecil Crampton.
George Blythe Cuthbert.
Peter Dodd.
Heber Duckham.
Alfred John Duncan.
Frederic MacDonnell Evanson.
Robert David Fitz-Gerald, Stud. Inst. C.E.
William Richard Flavin.
Frank Foster.
Robert Dixon Alison Frew.
Henry Augustus Garrett.
Jogindra Nath Ghosh.
Charles Grimston Gordon.
Albert Daniel Greatorex, Stud. Inst. C.E.
John Maxwell Sullivan Green, Stud. Inst. C.E.
Andrew Aitken Haddin.
Francis William Hardwick, M.A.
Charles Chetwode Hardy, Stud. Inst. C.E.
George William Hick.
Frederick William Hudson.
Albert Francis Jacob.
William Thomas Jones.
Charles Aldwin Kempson, Stud. Inst. C.E.
Robert Kendall.
Hugh Torrance Ker, Stud. Inst. C.E.
Charles Edward Knowles.
David Laidlaw.
Frederic Nix Latham, Stud. Inst. C.E.
Frederick Lowry.
Patrick Blackstock McGlashan.
James Mackenzie.
John Smith McNeill.
Howard Martineau, Stud. Inst. C.E.
George Henry Mee.

Associate Members—continued.

Johan Viggo Sigvald Muller.
Robert Andrew Munn.
Ernest Anthony Nardin.
Albert Edward Nichols, Stud. Inst. C.E.
James Palmer Norrington.
John Seabury O'Dwyer, B.A.Sc. (Montreal.)
Ashby Frederick Osborn, Stud. Inst. C.E.
Arthur Oughterson, Stud. Inst. C.E.
James Alexander Parker, B.Sc.
James Donald Paterson.
Alfred Pearce, Stud. Inst. C.E.
Henry Villiers Pegg, Stud. Inst. C.E.
James Robertson Porter.
Reuben William Roberts.
William Rossbach.
John Arthur Saner, Stud. Inst. C.E.
Frederick Walter Theodore Saunders, Stud. Inst. C.E.
Frederick George Shaw.
Edward Marsh Simpson.
Robert William Smith-Saville, Stud. Inst. C.E.
Henry Bath Spencer, Stud. Inst. C.E.
Arthur William Stilwell.
Pedro Suarez.
Sakuro Tanabe, M.E.
John Thomas.
Richard Eustace Tickell.
Auguste Touchon,
Thomas William Townsend Tuckey.
Nicholas King Turnbull, Wh.Sc., Stud. Inst. C.E.
William Waddell.
James Douglas Wallace.
Robert Warrack, Stud. Inst. C.E.
William Watson, B.A., B.E.
James Philip Webster.
Herbert Nicol Weldon, Stud. Inst. C.E.
William Hugh Williams.
Robert Anderson Wyse.
Cesare Zanetti.

Associates.

William Edwin Archdeacon, Staff Comm., R.N.
John McCormick.

(*Paper No. 2475.*)

"The Lansdowne Bridge over the Indus at Sukkur."

By Frederick Ewart Robertson, M. Inst. C.E.

Between Peshawur and Kurrachee, the North-Western State Railway crosses the Indus twice—once at Attock, near its exit from the hills, where the river is bridged by two spans of 308 feet and three of 257 feet; and again at Sukkur, where the Indus passes through an isolated ridge of nummulitic limestone, and is divided into two channels by the island of Bukkur. The rise of the river in time of floods is 17 feet, and the velocity 9 miles an hour.

The Sukkur Pass is bridged by three spans, of 278 feet, 238 feet, and 94½ feet respectively, which call for no special remark.[1]

[1] The timber staging used in the erection of these spans was described in the Roorkee Professional Papers, No. 10, vol. iii., July 1885.

The Rori channel is about 70 feet deep at low water, sloping down pretty steeply from the two sides, and is crossed by a single span, whose width at the site selected for the bridge could not be reduced below 820 feet. At the upper part of Bukkur island the channel could have been crossed by a span of 650 feet; but as the approach would then have cut right through the town of Rori, its increased cost, together with the heavy compensation for land, would have annulled the advantage of this route.

The steel superstructure for this span of 820 feet was designed by Sir A. M. Rendel, K.C.I.E., but its details, which would require a Paper to themselves, will not be alluded to further than is necessary to describe the erection. It consists of two single cantilevers, each having a projection of 310 feet, and carrying between them a central girder 200 feet in length. The entire steel-work of each cantilever was made in England, and was put together upon a timber scaffold in the maker's yard before shipment. The floor is of corrugated deck-plating, filled with wood, so as to give a cartway on the same level as the (single) railway, and there is a footway for men and for beasts of burden, corbelled out on both sides.

Plate 4 gives a general view of the span, and indicates the names by which the different members were distinguished. The foundation work consisted simply in clearing away the material down to the rock. The abutments are of Portland cement concrete, which was considered a better material than that furnished by any of the layers of Sukkur stone that would yield blocks of sufficient size for such work. The anchorages for the back-stays, or guys, are cellular structures, 32 feet by 12 feet by 6 feet, and are bedded in or behind the rock in cement concrete. The bedplates for the support of the cantilevers are also cellular, 20 feet by 10 feet by 8 feet, secured to the abutment by fourteen holding-down bolts, 9 feet long and 3 inches diameter; and for further security against horizontal thrust, they are concreted up solid to the rock behind.

The large vertical member called the "pillar" has a height of 170 feet, and comes almost to a point at the bottom. In the final erection of the bridge it had to be built with a backward rake of 6 inches, to give the requisite camber to the nose of the cantilever, and it was therefore necessary first to erect a staging to support it during construction.[1] This was built to the profile of

[1] Described in Indian Engineering of Nov. 5, 1887.

the back guys, and also served to erect them. The pillar was built up from the bed-plates, and the guy from the anchor, until they met at the top. The cover-plates in the last length of guy were left blank at one side of the joint, and the guy-plates were cut shorter to allow of making the joint at the actual temperature required to give the pillar 6 inches of backward rake at 100°, that being fixed upon as the normal temperature. The temperature in the sun runs up to 180°, and even at night often exceeds 90°. As the guy of the second cantilever was closed in much colder weather than that of the first, an allowance had to be made in the backward rake of the pillar, so as to keep the noses of the two cantilevers at the same level. After joining the pillar and guy, the next member to be built out was No. III strut. This is 230 feet long, and weighs 240 tons, and, being riveted to the bed-plate, it required some care to erect it without injury. The setting out, to keep it in line in both directions, was arranged as follows:—A sight-block with cross-wires was placed on each horizontal girder of the pillar against the front and the back leg; and when the cantilever was erected in England, a bull's-eye was painted and punch-marked on the spot where this sight cut No. III strut, and the exact position of sight-blocks was also marked. Re-aligning this sight gave the true position, both for line and for level. Measurements were also taken from certain places on the pillar to others on the strut, with a common tape and pocket spring-balance, a combination which will read to $\frac{1}{8}$ inch in 100 feet. For longer lengths than 100 feet a wire was used.

Fig. 9, Plate 6, shows the position of the ties used to support the strut during erection. The arrangements for the temporary ties will first be described. All these were of steel-wire rope, with a breaking-strain of 60 tons, the wire of which they were made having a strength of 135 tons per square inch; and as they were to be afterwards used in the suspension staging for erecting the "horizontal tie," they were all made of one length, with a strong thimble at each end.

Figs. 1 to 4, Plate 6, show the details of the attachment to the pillar and strut. Two 8-inch by $2\frac{1}{2}$-inch steel channel-bars, rather longer than the width of the pillar, were drilled with holes of uniform pitch, so that the bearing-plate and the bearings of the screws could be shifted to suit the taper of the pillar. The two screws were pitched such a distance apart as just to clear the pillar-leg; and the eye of the rope being shackled to one screw, it was taken round a stirrup of small channel-bar on the leg of the strut, and secured

to a loose tail of rope shackled to the other screw, by three cast-iron clamps, of which the detail is given in Fig. 4. All the ropes that were tested to destruction in England were held by this arrangement, and it never failed, nor could the slightest injury to the rope be detected. A ply of canvas was generally wrapped around them, and the precaution was taken to tighten up the bolts as the strain came on. The screws were made with a taper thread, and the nuts had a spherical seat to prevent any tendency to bend the screws. In putting on a new tie, the rope was first pulled as tight as convenient with a block and tackle; then the tail was clamped on, the slack coiled away in a convenient place, and the screws tightened until the new tie took all the weight, when the old one was removed. The working-strain adopted for the ropes was in all cases fixed at less than one-sixth of the breaking-strain, in order to avoid trouble from stretching. As the temporary ties had to be removed for use in building the "horizontal tie," and as it was also necessary to have the strut under control at the moment of junction, a special support, called the main tie, was employed for this purpose. The position and attachments of the main tie are shown in Plate 6, Fig. 9, and in Figs. 2 and 3; it consisted of four ropes doubled to each pillar, and coming to a bearing on the head of the pillar. For this bearing two 12-inch by 6-inch steel joists, a little longer than the outside width over the pillars, were laid across the heads, and were so arranged that they could be lifted by a hydraulic jack placed within, being guided by a couple of brackets bolted to the head of the pillar, as shown in Figs. 2, 3. Bars of iron, 4 inches square, were laid across the joists just clear of the pillar-head, the projecting ends being rounded to fit into an ordinary railway-coupling, of which three were strung together to assist in drawing up the ties. One end of the ties was shackled direct to the couplings, and the other end, after passing round a thimble 2 feet 6 inches in diameter, was clamped to itself by two of the cast-iron clamps before described. The main tie was attached to No. III strut by passing it round a couple of steel joists, laid against the upper legs, and packed up with wood to such a diameter as not to injure the ropes. To distribute the pressure, a chain, set up by couplings, was also taken from the joists to the lower legs of No. III strut.

The arrangements for erecting No. III strut are illustrated in Figs. 1 and 2, Plate 5. A staging to support the crane, and to guide the strut laterally, was built on the trimmer or girder of the roadway; but as this member was not nearly strong enough as a cantilever to carry such a load, it had to be supported from

below. A small temporary pier was therefore built in the river, and on this were placed iron cylinders, 3 feet in diameter, carried up to the level of the trimmers. The staging was then built on the trimmer, and on the staging was placed a double derrick crane, with sufficient sweep to build from the bottom up to the main tie. The wire-ropes of this crane were led away below to special winches, which also served other purposes, so that there was no gear on the crane itself. A piece of the strut, generally about 30 feet long, and weighing 5 tons, was lifted into its place, and held up by a $1\frac{1}{2}$-inch wire rope (7 tons breaking-strain), which was fitted with an eyebolt to put into a rivet-hole at the top until all the four were placed. Four distance-girders were next sent up, and the corners being thus connected a temporary tie was placed, after which the cross-braces were put on, and also the internal cross diaphragms, to keep the work square. Adjustment for line and level was next attended to, and then the riveting was put in hand. Most of the time was consumed in rigging up the small stages for the men to work on, as, owing to the shape and rake of the members, it was not found possible to arrange any form of staging to travel right up. After the strut had been built up beyond the reach of the double derrick, a pine derrick, 75 feet long, was erected on one of the main distance-girders between the legs. This was worked by three wire-ropes, one guy directly behind, and two side guys, passing through pulleys at the end of beams outrigged from the strut itself, all being attached to the special winches. The hoisting was done with an ordinary block and tackle from a steam-hoist; but owing to the great height, special coils of rope of double length had to be used. On the temporary pier, and bolted up against the cylinders on each side, were placed two Howe-truss cantilevers, to carry the inclined boom, which could not be conveniently supported from above, because it was outside the reach of the other members, as shown in the general plan. Thus the first and second lengths were supported, and the third length completed the junction with No. IV raker. On the completion of No. III strut, the span for the "horizontal tie" proved to be $\frac{5}{8}$ inch too much on one side, and $1\frac{1}{4}$ inch on the other.

The next operation was the erection of the "horizontal tie." This member is 123 feet span, and weighs 86 tons, and as lifting it in one piece was out of the question, it was decided to erect it on a temporary suspension-bridge or staging; but the suspension-cables being attached to the strut at one end, the bridge presented the difficulty of having a flexible abutment, for the horizontal pull

of the ropes when loaded was more than sufficient to counterbalance the weight of the strut by about 20 tons. As already mentioned, the ropes that first served as temporary ties for the erection of the strut were made of a suitable length for use in the suspension-bridge, and were provided with a thimble at each end and a screw-coupling to shackle thereto.

Figs. 6 and 7, Plate 5, illustrate the temporary suspension-bridge. There were on each side four ropes, each forming a complete loop, laid on cast-iron saddles on the head of the large pillar and No. III strut, so that each side of the bridge had eight supports. To ensure perfect uniformity of strain the ropes were first strung on the saddles placed upon the ground at approximately the correct span, and were adjusted by means of the couplings, until they all lay perfectly level at the lowest part. A mark was then scribed down the back of the saddle and the ropes, so that replacing them in the same position ensured the correctness of the dip, the couplings having been secured by a wooden chock, and the ropes marked for their respective positions. Planks suspended by an iron loop were next slid down the ropes, and these afforded a convenient platform for the men to work upon, and to arrange the trestles, which were simply pushed down to their proper places, and then held upright by the bracing. After this was completed, the planks which formed the temporary platform were removed. This suspension-bridge proved remarkably stiff, although during the erection the wind blew so strongly that the work was sometimes stopped by the camber-blocks being blown over. The tie was carried on sand-boxes, and all the pieces were laid in their places before the connections were made, so as to avoid any alteration in the figure, and consequent strain, by unequal loading of the bridge. The nose of No. III strut was loaded to the required extent to counterbalance the increasing horizontal pull of the bridge, by first slacking off the main tie, and then by adding load at the head.

For the erection of the horizontal tie, this temporary bridge carried two travellers of the form shown in Plate 5, Fig. 6, the lifting gear being simply a 5-ton differential block hung from a 3-inch round bar rolling on the two scantlings which formed the nose of the traveller. The pieces were raised by a derrick on the large staging behind, and passed under the noses of the two travellers, where they were laid hold of. As soon as the first triangle was completed on each side of the river, by joining the pillar and No. III strut, a system of overhead suspenders or carrying-ropes was at once fitted between the tops of the two

triangles, spanning the intervening gap, and serving for the erection of a great part of the main superstructure. This apparatus is shown in Figs. 5 to 8, Plate 6, and is the only special plant used on the work. The winches were placed upon the permanent steelwork of the horizontal tie, and were worked by a running rope, driven by a portable engine placed at the foot of the main guy. The drums were 5 feet 2 inches in diameter, and 2 feet 6 inches wide, and were driven by worm-gearing. There were three speeds, and the driving-shaft, which was fitted with one fast and two loose pulleys driven by a belt and crossed belt, could be also worked by hand. The wire-rope was attached to the drum, in the manner shown in Figs. 5, 6, being passed through a slit in the barrel, and held by clamps passing through the drum-head, so that the rope could be fastened at any point by over-running it, and coiling away the slack inside the drum like a tape.

The arrangement of ropes, &c., was as follows:—A gallows was erected on the head of No. III strut, carrying two pulleys, 4 feet 6 inches in diameter, in the line of each tie, and a saddle on the top for the fixed end of one rope to pass over, and furnished with a projecting arm which on one side of the river carried a pulley, and on the other side a saddle. Referring to Fig. 7, Plate 6, which shows the arrangement on one side of the river only, it will be seen that No. 2 rope is a carrying-rope leading from a winch on this side of the river, and fixed at the other side, while the corresponding rope from the winch on the other side is No. 4, passing over the saddle and fixed. Both sides have No. 1, which has a loose end, and is the guiding-rope passing over the second pulley. No. 3 is the outside rope leading from a winch at one side, and fast at the other, its particular duty being to suspend the bottom of the raking-pieces. A piece to be erected was suspended from runners on two ropes, and raised as a whole, the level of the piece being adjusted by winding on both ropes, or on one more than another; and it was guided by the third rope, which was hooked directly to it. Thus a tie-piece would hang from the two winches in line, but a raking member such as No. I strut would hang by the head from the pulley in line, and by the foot from the projecting pulley. The ropes used were of 36 tons breaking-strain. Underneath each pair of winches ran a countershaft across the horizontal tie, and these were actuated by the running rope driven by the portable engine, so that to start, stop, or reverse a winch, all that had to be done was to pull the striking-gear at a given signal. This running rope-gear, when once rigged up, did the whole of the work with the greatest

convenience, the pieces being drawn up by it until the rivet-holes met, and the finishing touches were then put in by hand. The largest piece lifted was the first joint of the inclined tie, 80 feet long, and 14 tons weight.

While the erecting-gear was in progress, No. IV vertical and raker were dropped down, and the trimmers (as the girders of the internal viaduct are called) were connected with the vertical; and from these again the inclined boom was reached, and built up piece by piece till connected with the raker, thus completing the first quadrangle.

The next step was to build No. II strut by a derrick from No. IV vertical, and then to connect it by erecting the inclined tie in the manner described above. The joint of the tie was first made good at the top, and then the head of the strut set to meet it exactly by the screws of the suspending-ropes already used as temporary ties for No. III strut. No. III vertical was next joined with the trimmer, and the boom carried forward to meet the raker as before; this series of operations being repeated for the remaining bays, except that the members had now become light enough to be picked up whole, as was done with No. I strut.

Two large barges of 400 tons burden, formerly belonging to the Indus flotilla, were of great service for these operations when the current permitted them to work. It should be explained that the difficulty in making use of such floating craft lies not so much in the mere force of the current (for a wire cable can be got of almost any strength), as in the quantity of debris that the river brings down from the caving in of the banks at certain seasons. Whole islands of timber-trees sometimes come down, and if they foul a mooring it can never be freed. In fact, any mooring in the stream is certain to be lost, the pressure being sufficient to completely flatten a 4½-inch rope in the hawse-pipe. These barges were fitted with a trestle, as shown in Figs. 3, 4, Plate 5, and with a large lifting-platform, which was so arranged that it could be adjusted at any height, to suit the different levels of the river, or of the work to be done. The barge was brought up in front of the bridge, and the piece to be lifted was pushed on board on rollers assisted by the crane. This crane was a 6-ton hand derrick-crane mounted on a high trestle, which ran on ways, so that if it was required to get the working platform under the bridge, the crane and trestle could be pushed back as far as required to clear the splayed-out booms.

On the completion of the cantilevers, their noses were exactly level. The line, or rather the middle position of the diurnal variation, was also correct. As the bridge lies north and south,

the effect of the sun on alternate sides used to make the nose vary nearly 1 inch either way. The Author has not been able to obtain a record of this variation since the bridge was completed. The width of the central gap was also correct at mean temperature.

It only remained now to erect the central girder. In designing the bridge in England, this was treated as a simple girder resting on rollers on the cantilever noses, and was arranged in such a way that it was impossible to build it out, as it had been taken for granted that it would be floated into position. This, however, was impracticable during six months in the year, owing to the violence of the floods, while the selection of a site on which to erect the girder so as to be accessible during the low season was also a very doubtful matter. It was therefore concluded that the span must be built on the cantilevers; and after studying various projects for transporting the completed girders—a method of erection which was rendered difficult by their height being more than that of the first overhead bracings of the cantilever, and also by the confined space at the nose—it was finally determined to use a staging built out and hanging from the cantilever noses, as shown in Figs. 7 to 11, Plate 5. This temporary stage is a deck bowstring-bridge 196 feet 8 inches in span, and weighing 56 tons complete, excluding floor planking. It comprises a full system of adjustable diagonal bracing under the floor, which is not shown in the drawing.

The end length of the top chord, with one post and bottom chord bars hanging, was first got up and hung from the cantilever by the links. Then the bottom chord was drawn across by the overhead gear and fitted; and the horizontal reaction necessary to convert it into a suspension bridge was obtained by means of a wire-rope and screws, from the back link shown in the drawings. On the pins were strung the stumps of the posts and of the diagonals. Next, a length of top chord, with the posts and long lengths of diagonals hanging, was sent out by the overhead gear and placed in position, each post being dropped over the stump belonging to it; and this operation was repeated until the bridge was completed, each bay being secured by the bracing as fast as it arrived. On the completion of the top chord, the back chains were slacked off, and the structure became a girder. This operation took seven days, and in carrying it out some little trouble was experienced in getting the diagonals into their couplings. As they were too stiff to spring, each diagonal had to be brought to meet the coupling, and then screwed up as the piece was lowered. This trouble might probably have been avoided by the adoption of a different form of connection for the diagonals.

The joints in the top chord, and in the foot of each post, and

other places which would generally be filled by rivets in a permanent structure, were made by cottered pins, shown in Fig. 8, Plate 5. These were found easy to handle, and were apparently as tight as a riveted joint. The wind-pressure was taken by a bracket bolted to the cantilevers, and bearing against check-plates on the last cross-girder.

The main girders were erected on sand-boxes, sufficient extra camber being given in laying out the bottom chord to allow for the deflection of the staging. On closing the main girders, the cross-girders and flooring were immediately proceeded with, the weight upon the staging being kept constant by slacking off the sand-boxes so as to keep the same deflection. The pieces were all run out by the overhead gear, and the main girder was erected, and the bottom chord riveted, in four and a half days.

The cost of the whole bridge was as follows:—

Items.	Sukkur Channel.	Rori Channel.	Total.
	Rs.	Rs.	Rs.
Approaches and stations	..	..	4,30,000
Foundations	1,60,000	2,76,000	4,36,000
Ironwork	1,99,000	17,01,000	19,00,000
Erection and painting	1,13,000	5,70,000	6,83,000
Flooring and railing	20,000	32,000	52,000
Staff quarters, workshops, sidings	..	..	27,000
Plant from England	..	..	91,000
„ from other works[1]	..	..	2,21,000
Boat service	..	..	10,000
Contingencies	25,000	37,000	62,000
	Grand total		39,12,000
Deduct value of plant in hand			1,70,000
	Net total Rs.		37,42,000

The English charges amounted to Rs.21,42,000.

The details of the charge for erection are as follows:—

		Rupees.
Labour		2,40,830
„ in Painting		5,140
Cordage, fuel, special plant		1,22,733
Carriage and repairs of plant		12,612
Large staging for pillar and guy—		
Labour	46,331	
Timber	1,52,783	
Stores	15,743	
Foundations	2,573	
	2,17,430	
Less credits for timber transferred	66,487	
		1,50,943
Staging for tie and on barges, and other false works		34,105
Photographs, &c.		3,792
Total Rs.		5,70,155

[1] Of this Rs. 67,300 was for carriage and new bottoms to the two big barges.

The present value of the rupee is about 1*s*. 5*d*. In addition to the above works, others to the amount of Rs.90,000 were executed for the Military Department.

The plant from England consisted of the following:—Four 6-ton derrick cranes, two portable 5-ton yard-cranes, two steam hoists, one set of riveting plant, wire-rope with specially large and strong pulleys, differential blocks, ordinary rope-blocks. The following items of plant were also supplied, but not being useful for transfer to other works were debited to the erection:—special winches and running-rope gear, ironwork for the gallows, screws and clamps for the attachments of the ties, bracing-bars for sundry trestles, special double crane for No. III strut.

Work was begun, with a few men only, on the anchors of the Bukkur cantilever in April 1887, and proceeded very slowly until September for want of ironwork. The bed-plates for the Rori cantilever arrived in November 1887, and from that date the work of erection was pushed forward until its completion. The staging for the central span was begun January 18th, 1889, and the girder closed February 9th. The bridge was tested March 19th, 1889, and formally opened March 27th.

The Paper is accompanied by five sheets of tracings, from which Plates 4, 5 and 6 have been prepared.

[APPENDIX.

APPENDIX.

WEIGHT OF THE PRINCIPAL MEMBERS.

	Tons.
Large bed-plates	55
Small "	4
Large pillars	183
Small "	7
Anchor	35
Guys	233
No. I. Guy supports	7
" II. " "	9
" III. " "	15
No. I. Struts	18
" II. "	36
" III. "	240
" IV. "	8
Booms	157
Horizontal tie	86
Inclined tie	80
Secondary tie	6
No. I. Vertical and raker	4
" II. " "	4
" III. " "	14
" IV. " "	62
Trimmers	90
Distance-girders and wind-ties	39
Cross girders	32
Roadway and railing	96
Total weight of the Bukkur cantilever	1,520
Add the Rori cantilever, of which the guy was 22 feet 8 inches longer	1,540
	3,060
Central span	256
Total	3,316

9 December, 1890.

SIR JOHN COODE, K.C.M.G., President,
in the Chair.

(*Paper No. 2483.*)

"The New Chittravati Bridge."

By EDWARD WALLER STONEY, M.E., M. INST. C.E.

AT a distance of 212¾ miles from Madras, the main line of the Madras Railway crosses the Chittravati River, and has for some years been carried upon a bridge of forty 70-foot openings spanned by plate girders. In this bridge, the abutments and ten of the piers on each side of the river had originally been built of masonry upon brick well foundations, while the remaining nineteen piers consisted of screw piles. The bridge was opened for traffic in 1868, and was partially destroyed by a great flood in October 1874, when nine of the masonry piers were undermined and overthrown. These were replaced by screw piles, and the structure has hitherto served to carry the traffic, but has now been superseded by the new bridge which forms the subject of this Paper.

The new Chittravati bridge has a total length of 2,680 feet, consisting of nineteen spans of 140 feet, from centre to centre of the piers. Its position, in relation to the old bridge, and also the diversion that was necessitated in the line of the Madras Railway, for a length of 1¾ mile, in forming the approaches, is shown in Fig. 16, Plate 7.

Fig. 1, Plate 7, is a geological section of the bed of the river. At the south abutment rock lies at a depth of 18 feet below the present bed, and dips gradually to a maximum depth of 80 feet at pier No. 17. Above the rock the deposits consist of varied and irregular strata of sand, gravel, clay, and large trap boulders, while mixed with the sand were found water-worn pebbles, and large fragments of rock, some sharp and others rounded.

The Chittravati River rises 80 miles above the bridge, and in this distance drains an area of 2,400 square miles. Its fall, at the bridge, is at the rate of 8 feet per mile; and its mean velocity and discharge during the flood of 1874 were calculated to have been

8·46 feet per second, and 114,625 cubic feet per second respectively, and it is believed that the sandy bed of the river was then scoured to a depth of 15 or 20 feet. As a rule, the river remains practically dry for about nine months in the year, although the water-level never falls lower than about 3 feet below the surface of the sand. This favourable circumstance was taken advantage of in the erection of the bridge; and the dry bed of the stream was made use of, not only for the transport of materials, but also for the erection of the iron-work, and for the operations connected with the sinking of the pier foundations.

Preliminary Works.

To facilitate the delivery of materials, a through siding was made alongside the main line at A C in Plate 7, Fig. 16; with branches to the stores and workshops, and also to the south end of the bridge, from which point three lines were laid across the whole width of the river-bed. Two of the lines through the river I Q, K O were kept parallel to the outside of the cylinder piers, 8 feet away, and on these ran and worked the cranes, dredgers, hoists, and other machinery, while a third I P was used for bringing up materials. These parallel lines were connected by cross-over roads L M, N O, and by traverser roads between the piers where required. They were protected from the action of floods by stones and boulders, from 6 inches to 12 inches in diameter, laid between the rails, and for a width of about 2 feet outside them; and with the exception of the rails sinking a little, and getting crooked, no material damage has been done to them.

South Abutment.

The abutments were built of coursed hammer-dressed masonry, of blue limestone, brought by rail from quarries 24 miles distant. Their construction is shown in Figs. 2, 3, 4, 5, and 15, Plate 7.

The south abutment, Fig. 15, was founded directly upon the rock by means of a cofferdam, which was designed to meet the existing practical conditions. The main piles, which were 20 feet long, were driven at a distance of 6 feet apart, and each pile consisted of a pair of double-headed 75-lb. rails, hooped together by wrought-iron bands. Behind these, planks 6 feet by 1 foot by 3 inches, with

planed edges, were pushed and driven down from the top as the excavation proceeded; and when the rock was reached, a wall of bags filled with clay was made upon it against the planks to exclude the outside sand. A water channel to the sumps was also formed with these bags, and two No. 8 pulsometers placed one at each end, beyond the newels, kept the dam dry. The rail piles were strutted transversely by old rails forced down between them to follow the excavation.

The rock, which dipped rapidly, was cut into rough steps, all loose parts removed, and the foundation levelled up with concrete, composed of 1 part of Portland cement, 2 parts of sand, and 4 parts of broken stone, by measure. The maximum head of water against the dam was 13 feet and the rock was covered by 11 feet of sand.

The cost of the cofferdam, including labour and materials, was Rs.1,736; and the entire cost of the excavation, including cofferdam, pumping and all charges, amounted to Rs.3 2a. per cubic yard of the net contents.

North Abutment.

As originally designed the foundations for this abutment consisted of seven brick wells on iron curbs, having an outside diameter of 12 feet; but as there was material to spare for cylinders, this design was altered, and three 12-foot cast-iron cylinders were used in the centre under the body of the abutment, with four brick wells, two under each wing wall, arranged as in Figs. 4 and 5, Plate 4.

In order to avoid the trouble, delay, and expense of loading these cylinders on the top with rails, they were sunk by weighting them with an internal lining of masonry set in cement mortar. The ring of masonry was carried upon an annular plate of cast iron, designed for this purpose (Figs. 12, 13, and 14, Plate 7), and fixed between two lengths of cylinder. By this means the permanent filling of the cylinders was made to do the useful work of sinking them. The weight of the masonry ring, before immersion, was about 4 tons per lineal foot of the cylinder.

Priestman's grabs were used for dredging out the material, the sinking being continued until the cylinders reached the bed of boulders at a depth of 60 feet below the surface. The excavation was then carried on by divers, until the cylinders were sunk to a bed levelled in the rock at a depth of 66 to 68 feet.

The brick wells were built on wrought-iron curbs, as shown in Figs. 7 to 11, and were sunk by means of Wild's and Priestman's dredgers, and loaded with 75-lb. rails, 20 feet long. The load

required consisted of 300 to 1,300 rails, in addition to the weight of the well itself, which varied from 150 to 288 tons.

The wells were carried down to the boulders and were bedded by divers at a depth of 60 to 63 feet below the surface. Considerable trouble was experienced in sinking them, as they were firmly held by the top stratum of stiff clay, which was 27 feet thick. It sometimes happened that a hole had to be dredged in the centre 14 to 20 feet below the cutting edge before the well could be made to sink, and in such cases the outside sand would often rush in, forming a crater all round. In consequence of these slips, some of the wells were drawn out of plumb, and one under the west newel canted outwards, so that when sunk to the proper depth it came in the way of the next well, which struck upon its curb during the process of sinking and could not be got any deeper. This incident illustrates the necessity of leaving ample room between any contiguous cylinders which have to be sunk to considerable depths, so as to prevent their coming in contact if they get slightly out of plumb. The tops of the wells and cylinders are adjusted at a level 6 feet below the river-bed, and are united by arches on which the superstructure of the abutment is carried up.

Instead of providing large stones for the girders, a box 4½ feet by 4 feet by 2 feet was left in the masonry, and was filled with Portland cement mortar of 1 part of cement to 2 parts of sand, on which the bearings were fixed. These cement bed-blocks have answered very well, and are cheaply and easily made.

CYLINDER-PIERS.

Each of the eighteen river-piers consists of a pair of cast-iron cylinders, placed 18 feet apart, from centre to centre, and braced together at the top by a deep and massive box of plate and angle-iron. Their construction is illustrated in Fig. 2 and in Figs. 11 to 21, Plate 8.

The cylinders have a diameter of 12 feet throughout the lower portion, to within 9 feet of the river-bed, at which point a conical tapering length is inserted, reducing the diameter to 9 feet. The 12-foot portion was made in lengths of 6 feet, each length being cast in six segments with 1¼ inch thickness of metal, strengthened with internal flanges and feathers, and united by 1¼-inch bolts. The joints were caulked with iron-rust cement to within ¾ inch of

the inner edge, this space being filled with a mixture of 1 part of sand to 1 of Portland cement to make the joints air-tight and fit for pneumatic work.

Each cylinder was furnished with a special bottom length of wrought-iron, forming a cutting-ring 3 feet in height built of ⅝-inch plates. The cutting-rings, after being riveted together, were placed accurately in position on the dry river-bed, and were sunk 2 feet 6 inches by men digging inside them. Two lengths of cast-iron cylinder were then erected upon each cutting-ring, and when they had been bolted and caulked, a Priestman's crane and dredger, standing on the working lines of railway in the river-bed, continued excavating until the top had been sunk to the level of the ground. Two additional rings were then built up, forming a second length of 12 feet, and provision was now made for weighting the cylinders by placing across the top two pairs of hardwood beams 18 feet by 18 inches by 18 inches, on which the 75-lb. rails were stacked. The load varied from 200 to 1,120 rails, according to the depth of the cylinder and the nature of the strata it passed through. With large loads the height of the stack above the river-bed was often as much as 27 feet, so that the Priestman's dredger could not be used, and Wild's, Bell's, or Bull's dredgers were employed, being worked by steam-hoists by means of derrick poles.

All these dredgers answered well in sand, but the progress was slow when there were many pebbles or boulders, as these frequently came between the teeth of the dredger, a small stone being sufficient to allow all the sand to escape. Several boulders of 3 to 5 cubic feet were brought up; the largest measured 9 feet in length by 5 feet in girth, and was caught and hauled up by a Priestman's dredger. None of these dredgers were of the slightest use in clay, even of moderate stiffness. In a few instances some sinking was done by pumping out the cylinders with pulsometers and digging out the clay; but as the material was often more or less sandy, the outside sand sometimes rushed in, and in one case filled the cylinder for a height of 27 feet. The greatest height from water-level to the discharge-pipe of the pulsometer was 64 feet. All the cylinders, with the exception of pier No. 11, were bedded on the solid rock, the bottom being dressed level by divers or with the aid of pneumatic apparatus, except in the case of piers Nos. 7 and 8, which were kept nearly dry by pulsometers, and in which the rock was dressed level by stone-cutters.

As far as pier No. 9 the sinking and bedding of the cylinders was comparatively easy, but beyond this point all the piers gave

considerable trouble, especially Nos. 10, 11, 12, 13, and 14, as the bed-rock was here covered by a depth of from 7 to 22 feet of boulders, the largest taken out unbroken being 5 feet long by 11 feet in girth, and containing about 45 cubic feet. When large boulders were met with under the cutting-edge it was a difficult matter to remove them safely. If they were pulled into the cylinders it generally happened that a blow of sand would follow; and when the projections were cut off by blasting, the cylinders were sometimes cracked by the dynamite, although the charges used were small; while the drilling of the holes by divers was always a tedious operation.

An average of 6 feet a day in sand could be excavated by dredgers, while from ½ to 1 inch a day was about the rate of sinking through boulders by divers. The use of small charges of from 1 to 2 ozs. of dynamite fired on the bottom of the holes dredged or excavated by divers was found to facilitate the work, as the tremor and vibration set up by firing them enabled the load to overcome the friction, so that the cylinders sank with a smaller load of rails than would otherwise have been required, starting in most cases directly after the explosion, but occasionally from two to five minutes later.

When a 12-foot cylinder was sunk to within about 8 feet of the anticipated rock-level, as shown by the borings, the taper-piece was put on with a 9-foot diameter ring on the top of it, as the design provided that 9-foot rings should be used from just below the river-bed to the pier-tops. The borings unfortunately proved incorrect, rock being met in places at a higher level than was expected, and in such cases the taper-pieces, and perhaps one or two rings below them, had to be dug out and readjusted to allow of the former being got low enough to put the bracing-box in place.[1] This trouble would have been saved if the 12-foot cylinders had been carried right up to the top, which would also have allowed more room for adjusting the girder-bearings when the cylinders happened to cant or draw away from their true position. This frequently occurred when the cylinder struck a boulder or some hard material on one side, and in pulling it upright it was more or less displaced. It is practically impossible to sink cylinders to depths of 60 or 80 feet in the exact position they should occupy, and for this reason ample diameter should be given to allow room for setting the bearings true to centres.

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[1] In one case, at pier No. 3, the cylinders were pulled bodily up 12 feet from a depth of 25 feet, by six 60-ton hydraulic jacks.

Piers Nos. 12, 13, and 14, were bedded by the aid of pneumatic apparatus, but the operation was slow and expensive, owing to the repeated failure of the air-pumps, which were of an old pattern and much worn. The difficulties experienced at pier No. 11 were more serious than at any other part of the work, in consequence of the great depth (22 feet) of the bed of large boulders here met with. In sinking the cylinders through these boulders divers were employed at first, but they only succeeded in sinking the left cylinder 10 feet in six months, working 603 shifts, and the right cylinder 7 feet 4 inches in five months, working 429 shifts, or at an average rate of 1 foot in 60 shifts of four hours each. In consequence of this slow rate of progress pneumatic apparatus was substituted, and when the cylinders were laid dry it was found that some of the segments of the lowest ring had been cracked by the dynamite charges before alluded to, and permitted a leakage of air, which gave some trouble. A luting of stiff clay was used to stop the cracks.

When working in the left cylinder by the pneumatic process at a depth of 60 feet a loud report occurred, and it was found that two segments had cracked in a line with the cracks in the lower ring, originally caused by the dynamite, thus making a continuous fracture 18 feet high. Pneumatic work was then stopped, as it seemed unsafe to continue the air-pressure; and a hole 10 feet in diameter was sunk by divers to get down to the rock bed. But when the bed which had been touched by the borings was reached, it proved to be only a superficial layer 9 inches thick, and under this large boulders were again found. In getting out one of these from under the cutting-edge an inrush of sand occurred, which filled up the cylinder for 15 feet. It was then decided to stop further sinking, clear out the sand and put in the concrete, which was done successfully.

The right cylinder took eight and a half months, and the left eleven and a half months, to sink through 22 feet of these boulders. These particulars show how difficult it is to forecast the time required for such foundations, as the mishaps experienced at one pier may upset all calculations derived from the progress on the others.

The recorded details of the loading of the cylinders, and of the average resistance in sinking, are given in the Appendix.

Divers' Work.

In all 168 lineal feet of cylinders were sunk, chiefly through boulders, by native divers in 4,274 shifts; this gives an average of 25·4 shifts per foot. Similarly 35 feet of 12-foot wells were sunk by divers in 1,068 shifts, or an average of 30 shifts per foot. The rock at the bottom of thirty-two cylinders was dressed level by divers in 1,621 shifts, or an average of fifty shifts a cylinder; as the rock dipped rapidly, this bedding generally involved cutting away at least a depth of 2 to 3 feet of rock, or about 8 to 12 cubic yards. The rock was an indurated clay slate.

An account was kept of the quantity of material excavated during each shift, and the general results obtained from a total of 27,988 hours' work, in 6,997 shifts, is given in the Appendix. The average number of cubic feet excavated in a shift by a single man working by contract, or by day labour, was as follows:—

Soil.	Contract.	Day Labour.
Sand	7·13	10·65
Clay	5·89	..
Boulders	5·91	7·68
Rock	7·88	5·36
Sand	7·32	8·83
Clay, Sand, and Pebbles	7·12	2·44

Dredging Cylinders.

The greater part of the work was done by two of Priestman's double-chain dredgers of 15 cubic feet capacity, weighing when full about 2·2 tons each. The greatest depth of 12-foot cylinder ever sunk by one of these dredgers in a day was 12 feet 6 inches in sand, the average being 5 feet 6 inches. Besides these, Wild's single-chain dredger of 10 cubic feet capacity, and Bell's and Bull's dredgers of the same size were used. All these worked well. In one month 300 lineal feet of cylinder were sunk, and this was the maximum attained.

Cost of Cylinder-Sinking.—The total amount of cylinder sinking executed by each of the methods above described, and the average cost of sinking per lineal foot, including fuel and supervision, were as follows:—

	Lineal Feet of Sinking.	Cost per Lineal Foot.
By dredging	1,323	9 rupees.
By pulsometers	112	85 "
By pneumatic apparatus	46	443 "
By divers	168	162 "
Sinking cutting-rings by hand-labour	124	5 "
Total . . Feet	1,773	

The total cost of erecting and sinking 1,773 feet of cylinders, including all charges except the original value of machinery, amounted to Rs.56 8a. per lineal foot.

Concreting Cylinders.

For the first 4 feet in depth the concrete was composed of 1 part of Portland cement, 2½ parts of sand, and 4 parts of stones broken to 1½ inch cube, the concrete for the remainder of the cylinders to within about 6 feet of the river-bed being composed of 1 part of cement, 2½ parts of sand, and 6 parts of stone measured dry; the cement and sand were first mixed dry, then made into mortar, after which the stone was added. The material was lowered through the water in skips until a sufficient quantity had been deposited to make the cylinder almost water-tight. This was allowed to set for a week, and the cylinder was then pumped dry, the concrete for the remainder being put in by hand and rammed in thin layers. Taking the average of all the cylinders, a depth of 18 feet of concrete at the bottom was required to staunch them, and the top of this was at an average depth of 30 feet below water-level in the river; but these dimensions varied greatly in the different piers, the maximum depth being 50 feet below water with 3 feet of sealing.

Although the concrete set quite hard, and was very dense, the river-water percolated through it as well as alongside the cylinder ribs. The Portland cement was supplied by several English makers, and there was a considerable difference in the behaviour of the various samples; one in particular left after each days' work a quantity of slime or slurry over the concrete, and when the cylinder

was baled out, after a thickness of 30 feet had been deposited under water, it was found that the slurry extended to a depth of 8 feet. Below this the Author expected to find stone and sand instead of concrete, but on being cleared, washed and examined, it was found to be set quite hard. The other cements used never left more than 6 inches to a foot of such slime on the top.

The concrete cost in place Rs.14 5a., or about £1 per cubic yard, the materials costing Rs.13, and the labour Rs.1 5a.

Above the concrete the cylinders were filled to within 3 feet of the summit with hammer-dressed masonry of fine flat-bedded limestone, set in mortar composed of 1 part of lime, 1 part of sand, and 1 part of surki, the masonry costing about one half the price of the Portland cement concrete. The last 3 feet of filling was formed of 1 part of Portland cement to 2 parts of sand, and on this the cast-steel roller bearings were bedded and fixed by lewis-bolts.

Bracing-Boxes.

Each of these was sent out in two pieces of the form and dimensions shown in Plate 8.

In order to fix them in position, the 9-foot cylinder-rings were put in place and fixed together with a few bolts in each segment; the halves of the bracing-box were then lifted by a derrick-pole and crab-winch, and held accurately in place, while the two top bolt-holes were drilled on each side. In these holes short bolts were fixed, and the remaining bolt-holes were then drilled in the cylinder segment. The two halves having thus been fixed, the cover-plates were bolted on by holes on one side of them, those on the other side being drilled in place. All cover-plates, etc., were then service-bolted and riveted up, after which the four outside segments of each 9-foot cylinder were taken down, in order to provide room for the erection of the girders. For the fixing of each bracing-box two hundred and sixty-four holes had to be drilled, and three hundred and seventy-two rivets put in. After the cylinders were finished and concreted, each bracing-box was filled with concrete.

Girders.

The superstructure is designed for a single line, the girders being of the Murphy-Whipple type. Each span has a length of 139 feet

8 inches over all, or 136 feet from centre to centre of the bearings, with a working depth of 16 feet, and a width of 16 feet 7 inches in the clear, or 20 feet 3 inches over all. The weight of a span is 146 tons 12 cwt., or a little more than 1 ton per foot. The booms came from England in five pieces, while the lattice-bars, cross-girders, rail-runners, struts and pillars were each sent separately. Taking advantage of the fact that the river-bed was safe to work in for about nine months in the year, the Author was enabled to get the spans erected upon the ground, each in its proper position, and afterwards lifted into place. For this purpose camber-blocks were placed at the ends and under the shipment-joints of the girders, and were supported on sleepers laid directly upon the river-bed, their level being so adjusted as to keep the underside of the bottom boom 2 feet 6 inches to 3 feet over the river-bed, so that a great portion of the riveting could be done at the most convenient height for working.

The bottom booms were first placed, and the cross-girders bolted up, after which the end-pillars and vertical struts were put in and joined by their respective diagonal tension-bars; then followed the top boom and overhead struts, and when the whole had been secured in place and the joints screwed up by service-bolts, the riveting was commenced. This was all done by native workmen, and in each span there were 10,216 rivets of $\frac{7}{8}$ inch diameter, besides 1,120 rivets of $\frac{3}{4}$ inch diameter.

The blocks were set to have a camber of 0·23 foot at the centre; after erection levels taken on the girders showed the average actual camber to be 0·157 foot, the maximum being 0·17 foot and the minimum 0·13 foot. The rails were laid without camber, the longitudinal teak timbers on which they rest having been dressed level *in situ*, their thickness increasing gradually from the centre to the ends of each girder. The girders are supported at one end by a fixed cast-steel rocker and at the other end by a combined rocker and roller, so as to allow of expansion. Details of these bearings are shown in Figs. 4 to 10, Plate 8.

As soon as the riveting was finished, a 60-ton hydraulic jack was placed under each end pillar, and the entire span was lifted from the river-bed to a height of 9 inches above its final level, the lifting being done at the rate of 4 to 5 feet a day. During this operation the ends of the main girders were, of course, occupying a position in the centre of the 9-foot cylinders, from which the outer segments had been removed as before mentioned and as indicated in Fig. 20, Plate 8; and as soon as the girder was raised high enough the cylinder segments were successively replaced;

and by the insertion of packing, the ironwork was kept always supported on the cylinders, safe from risk of floods or freshes. This method of erecting the girders proved very convenient, expeditious and economical, as no false staging was required, and the bulk of the work was done and inspected from the dry river-bed. It also allowed as many spans to be worked at as there were piers finished to support their ends.

An abstract of the principal items of work done in the bridge is given in the Appendix. The first cylinder was pitched on the 23rd of April, 1888, and the bridge was fully finished and opened for traffic on the 6th of March, 1890; so that the time occupied in actual construction was a little over twenty-two months. The entire cost amounted to Rs.480 per lineal foot of bridge, or £38 at current rate of exchange; the cost of supervision, including engineers' salaries, office establishment, &c., was 2·71 per cent. on the outlay. The total cost of the bridge was Rs.12,81,200 = £101,428, and of the approaches Rs.54,341 = £4,302.

Fig. 1.

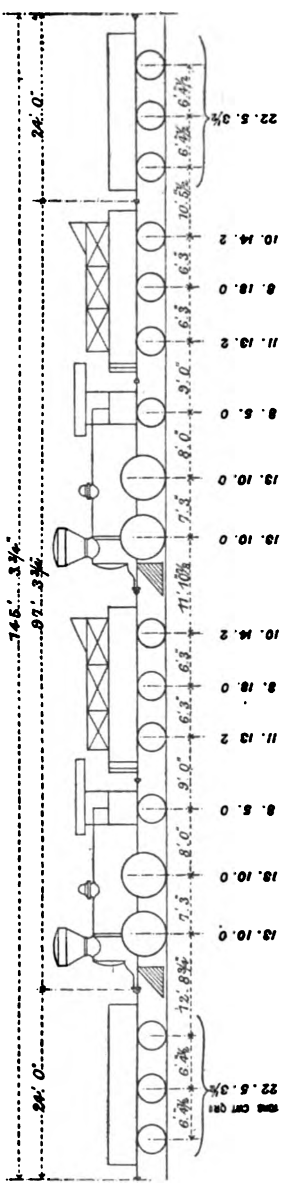


DIAGRAM OF TESTING ENGINES.

The girders were tested with two of the heaviest engines and tenders in use on the Madras Railway, weighing together 177 tons 13 cwt. 3 qrs., the dead-load being 159 tons 8 cwt. 2 qrs. The test-

load was therefore equal to a live-load of 1 ton 6 cwt. 1 qr. per foot, and a dead-load of 1 ton 3 cwt. 2 qrs. per foot, or a total of 2 tons 9 cwt. 3 qrs. per foot. The deflections of the several spans were singularly uniform, the average under a standing-load being 0·43 inch, and when running 20 miles an hour 0·49 inch.

The bridge was designed by Messrs. Hawkshaw, Son, and Hayter, by whom the ironwork was sent from England. The laying out of the work, and its entire management and supervision were entrusted to the Author, by Messrs. W. R. Robinson and H. R. P. Carter, MM. Inst. C.E., Engineers-in-chief of the Madras Railway.

The Paper is accompanied by numerous drawings, from which Plates 7 and 8 and *Fig. 1* have been prepared.

[APPENDIXES.

APPENDIXES.

APPENDIX A.—SUMMARY OF THE MAIN ITEMS OF WORK DONE AT CHITTRAVATI BRIDGE.

Description of Work.	Unit.	Quantity.	Total.
Cast-iron work in cylinders	Tons	2895	6211
Wrought-iron work in girders	„	3316	
Cylinder sinking below river-bed	Lineal feet	1772	
Lineal feet erected above river-bed	„	541	
Lineal feet of wells below river-bed	„	446	
Cylinders bedded	No.	36	
Brick- and cylinder-wells, bedded	„	7	
Concrete in cylinders	Cubic yards	5359	6179
„ in north abutment	„	582	
„ in south abutment	„	40	
„ in bracing boxes	„	198	
Masonry in cylinders	„	2391	4497
„ in three wells, north abutment	„	442	
„ in abutments	„	972	
Brickwork, four wells, north abutment	„	692	
Timber work for rail-runners fixed in place	Cubic feet	2302	4888
Joists	„	2586	
Teak-wood planking	Square feet	23940	

APPENDIX B.—LOADING CYLINDERS. FRICTIONAL RESISTANCE, &c.

An account was kept of the loads put on each cylinder and well, and from these a number of calculations as to the surface frictional resistance have been made.

The data obtained in sinking cylinders by the pneumatic apparatus ought to give very accurate results, as the interior of the cylinder was cleared and undercut to a depth of 3 feet below the cutting edge; the air was then allowed to leak off, and the pressure at which the cylinder sank was noted. Therefore at the moment when the cylinder began to move the external load just overcame the cylinder surface friction, plus residual air-pressure.

The results of nine experiments, made in this way, are given in Table I.

TABLE 1.—LOADING OF CYLINDERS SUNK BY THE PNEUMATIC PROCESS, AND FRICTIONAL RESISTANCE IN SINKING, AS FOUND BY NINE EXPERIMENTS IN THE CYLINDERS OF PIERS 11 AND 13.

—	Pier 11. Left Cylinder. A.	B.	C.	Pier 11. Right Cylinder. A.	B.	C.	D.	E.	Pier 13.
	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft In.	Ft. In.
Imbedded depth of cylinders: sand	33 2	33 2	33 2	33 2	33 2	33 2	33 2	33 2	33 8
" " " clay	10 2	10 2	10 2	10 2	10 2	10 2	10 2	10 2	10 0
" " " sand and clay . .	7 3	7 3	7 3	0 8	4 6	7 3	7 3	7 3	1 0
" " clay and boulders.	5 8	7 5	9 1	..	..	7 11	7 11	12 5	2 4
Total	56 3	58 0	59 8	44 0	47 10	58 6	58 6	63 0	52 0
Area of imbedded cylinder surface, square feet .	2,165	2,232	2,296	1,693	1,841	2,251	2,251	2,426	1,960
Load employed, weight of cylinders, in tons .	78·28	..	..	70·23	70·23	85·12	78·27	78·27	70·83
" " " rails "	222·22	..	..	173·33	248·88	222·22	222·22	222·22	229·70
" " other extraneous load "	10·30	..	..	4·74	4·74	4·74	4·74	10·30	10·30
Total load "	310·80	310·80	310·80	248·30	323·85	312·08	305·23	310·79	310·83
Lifting force, due to air-pressure observed "	40·32	44·64	44·64	..	..	..	..	..	49·10
Net sinking force "	270·48	266·16	266·16	248·30	323·85	312·08	305·23	310·80	261·73
Frictional resistance per square feet of imbedded cylinder surface . . . } in cwt.	2·50	2·38	2·32	2·93	3·52	2·77	2·71	2·56	2·67

The average surface-friction, as deduced from the load actually used in sinking the cylinders, whether by pneumatic or other process, is given in Table II in cwts. per square foot of imbedded cylindrical surface.

TABLE II.—SURFACE FRICTION OF CYLINDERS AS DEDUCED FROM THE LOADS ACTUALLY USED IN SINKING.

—	Cwts. per Square Foot.		
	Mean.	Maximum.	Minimum.
Average of thirty-six cylinders sunk to depths varying from 10 feet to 27 feet and averaging 19 feet, under their own weight only, which varied from 25½ to 33 tons, and averaged 31 tons	0·85	1·33	0·63
Average of one hundred observations in sinking thirty-six cylinders, at depths varying from 17 to 64 feet, under a load of rails varying from 31 to 249 tons and averaging 132 tons besides the weight of the cylinder	2·13	4·08	1·29
Average of nine observations in sinking three cylinders by pneumatic process, at depths varying from 44 to 63 feet, as shown in detail in Table I	2·71	3·52	2·32

TABLE III.—WORK DONE BY DIVERS PER SHIFT AT CHITTRAVATI BRIDGE, TAKING THE AVERAGE OF THEIR ENTIRE WORK IN SINKING AND BEDDING CAST-IRON CYLINDERS 12 FEET IN DIAMETER.

—	Sand.	Clay.	Rock.	Boulders.	Pebbles.	Sand and Pebbles.	Sand, Clay, and Pebbles.	Clay and Pebbles.	Sand and Rock.	Sand and Stone.	Clay, Sand, and Stone.
	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.
Maximum . . .	57	18	13½	9	2	40½	18	3	6¾	27	23
Minimum . . .	2	1	1	½	1	1	1	2	2¼	2½	2¼
Average . . .	29½	9½	7¼	4¾	1½	20¾	9½	2½	4½	14¾	12½

Discussion.

Sir John Coode, President, thought it would be admitted that clearer descriptions of executed works, of the difficulties encountered, and of the mode in which those difficulties had been overcome had rarely been put before the Institution. Their thanks were eminently due to the Authors for their most interesting and instructive Papers. Sir John Coode.

Mr. Harrison Hayter, Vice-President, said that he was responsible for the design of the new Chittravati bridge on the Madras Railway; but before noticing a few features to which he would presently draw attention, he would briefly allude to circumstances connected with the Madras Railway, bearing upon some of the bridges. That line, which was between 800 miles and 900 miles long, crossed in its course several valleys, many of which were of the nature of the Chittravati Valley—that was to say, they were wide, with little or no water in the channels during a period of about nine months, but for the rest of the year they were more or less flooded. The porous material of the beds of the rivers, however, was at all times charged with water below the level of some 3 feet from the surface. The Madras Railway Company was incorporated in 1853, and at the outset the line was laid with rails weighing 65 pounds per lineal yard, and worked by locomotive engines with 10 tons only on the driving axle. Other works were to a great extent in proportion. It was, in fact, what would now be looked upon as somewhat of a light railway, although not regarded as such at the time when the works were designed. He did not wish to imply that the pioneers of the line were not justified in thus fixing upon the type of its construction, especially as at this early stage of railways in India their success was by some considered problematical. Owing, however, to the great extension of the system and of the increase of traffic, the Madras Railway had become one of the most important lines in India, and had now a heavy permanent way, and was worked with locomotive engines as powerful as any in that country. Some of the bridges, however, were not in so satisfactory a state as could be desired. Most of them had spans of 70 feet, measured from centre to centre of the piers. Some had been strengthened or reconstructed, and a few still remained to be dealt with. In some cases the 70 feet spans had been retained, but in the Chittravati bridge and others, Mr. Hayter.

Mr. Hayter. where the piers had to be sunk to considerable depths, it was less costly to double the spans, making them 140 feet from centre to centre of the piers; and this was a type that suited the conditions. There were one or two matters of detail in the design of the Chittravati bridge to which Mr. Hayter would allude. It would be noticed that the cylinders of the piers were of cast-iron, excepting the bottom length, which was of wrought-iron (Plate 8, Figs. 15–19). This had resulted from experience gained during the construction of the Charing Cross bridge, designed in 1860, carrying the Charing Cross branch of the South Eastern Railway across the River Thames. The cylinder-piers of that structure were of cast-iron from top to bottom, sunk in the London Clay; and, notwithstanding that the bottom length was made thicker, when a bed of septaria was met with in sinking, this bottom length cracked in places, giving trouble, and involving some additional cost. Since then—excepting only in the case of the Cannon Street bridge, where the bottom length was much thickened—his firm had always made at least the bottom length of the pier cylinders of bridges of wrought-iron. In the Chittravati bridge this bottom length was 3 feet deep, and made sufficiently strong to absorb any strain that would come upon the cylinders during the process of sinking. It would also be noticed that the top length of the cylinders was an adjusting piece or cap of cast-iron 2 feet 2 inches deep (Plate 8, Figs. 14 and 15). Every one in the habit of sinking cylinders knew the importance of such a provision. Being of a larger diameter than the cylinder, it could be moved up or down, and bolted through to the cylinder exactly where required, forming at the same time a suitable projecting terminal cap to the column. This adjusting cap was filled with strong Portland cement concrete, carried up a little above the casting, and splayed all round, so that the longitudinal girders would nowhere touch the casting, but would bear entirely on the concrete. The north abutment of the Chittravati bridge was designed to be founded on brick wells; but these were only partially used, because there were some spare cast-iron cylinders at hand. The brick wells were built upon a strong wrought-iron curb (Plate 7, Figs. 7–11), sent from England, and there were through bolts extending from the bottom to the top, with wrought-iron continuous bond-rings, or circular washers, at vertical intervals of 15 feet passing round the central circumferential line of the brick well. In this way the curb could not separate from the brickwork, nor could the brickwork break away, both forming, as it were, one solid piece. The outside diameter of the curb was

Mr. Hayter.

12 feet 3 inches, and it was 3 feet deep. The outside diameter of the brick well was 12 feet, and the circular bond-ring 4 inches wide by ⅜ inch thick. The Author clearly described the process of sinking the wells. All who designed bridges to be erected in India knew the importance of duplicating parts as much as possible. All corresponding pieces of the Chittravati bridge, and of other bridges, were therefore made so that they might be interchangeable. That was essential in places away from any manufacturing centre, and where the failure of an important part might cause a delay of weeks, or even months; but by sending out a few extra pieces, the contingency could be effectually met. He had nothing to do with the erection of the Chittravati bridge beyond arranging as to the plant to be sent from England, and seeing that it was properly manufactured. The credit of the erection was due to Mr. Stoney, who carried out the work in a satisfactory and workmanlike manner. Mr. Hayter had received an official document, issued by the Public Works Department of the Government of Madras, containing a report by the Government Consulting Engineer for Railways on the inspection of the Chittravati bridge, in which, after praising the quality of the work, he said, "As regards cost and time occupied in completion, it beats any record, at least in Southern India." This was somewhat remarkable, because the bed of the river was full of boulders, no less than 1,800 cubic yards having been removed from the inside of the cylinders, some of them weighing as much as two tons, a circumstance which would add much to the difficulty and to the cost of erection. The Governor of Madras also issued the following order:—"His Excellency, the Governor, in Council records with great pleasure his high appreciation of the professional skill exhibited by Mr. E. W. Stoney on the construction of the new Chittravati Bridge." Mr. Hayter would give a few figures which would be found generally useful. The cylinders, excluding the concrete filling, cost to sink Rs. 56½ (about £4 10*s.*) a ton—the tonnage included the weight of all the ironwork from the bottom of the wrought-iron bottom length to the top of the adjusting cap, with all the bolts and fastenings, and the money included all charges except carriage from Madras and plant. The girders cost to erect Rs. 3,487 a span, or Rs. 22½ (about £1 16*s.*) a ton, which included also all charges except carriage from Madras and plant. The cost per lineal foot of the bridge, including the provision of the material in England, transport and erection in India, supervision, and depreciation of plant, taking the rupee at the current rate of one shilling and sevenpence, was a little over £38.

Mr. Hayter. The average depth of cylinder sunk per working day was about 9 feet. He gave these figures because they were just those required to assist in framing an estimate of like structures in like situations. It was worth while also to record that a little more than one half of the total cost was due to the provision of the ironwork, metal-work, and Portland cement sent from England and delivered in Madras, the remainder to the work transported from Madras to the spot of erection, and erecting it in place complete in every respect. The prevailing rates of manufactured ironwork were low at the time the Chittravati bridge was let in England. The cast-iron work in the substructure was procured at £4 12*s.* a ton, and the wrought-iron bottom length and the bolts and nuts at £12 18*s.* 10*d.* a ton. The wrought-iron work in the superstructure cost £9 5*s.* per ton, and the steel bearings £23 17*s.* 6*d.* a ton, all delivered in London. The superstructure was let to Messrs. Head, Wrightson & Co., of Stockton-on-Tees; and it was in a measure owing to the good workmanship that the tests to which the bridge was subjected after erection, and which were singularly uniform, proved so satisfactory. The testing load consisted of two locomotive engines with tenders, each locomotive engine with tender weighing 66 tons 11 cwts., and of two loaded rail-wagons, each weighing 22 tons 5 cwts. 3 qrs. The testing load applied, together with the dead load of the bridge, did not produce a strain in any part of the material beyond the stresses specified by the Government of India. The Author, in Table II of the Appendix, gave some information as to the surface friction of cylinders in sinking. Mr. Hayter directed attention to this, as it was instructive and likely to be useful. Mr. Stoney had remarked on the inability of the ordinary grab to remove any but very soft material from the inside of cylinders; and this coincided with Mr. Hayter's experience. The implement had, however, been improved by Mr. William Matthews, M. Inst. C.E., who added an upper weight and side tines; and this tool would excavate stiff clay from the inside of cylinders. The capability of grabs was referred to by him (Mr. Hayter) and by others in the discussion on the paper of "Dredging Operations and Appliances,"[1] and he only now briefly alluded thereto as bearing upon and in confirmation of the remarks made by Mr. Stoney in his Paper on the Chittravati bridge.

Mr. Robinson. Mr. W. R. Robinson said that, having been chief engineer of the line during a portion of the time that the Chittravati bridge was in construction, he might say a word upon one or two points

[1] Minutes of Proceedings Inst. C.E., vol. xxxix. p. 43.

mentioned by the Author. With reference to the contiguity of the wells, the Author recommended that they should not be placed too closely together. He could thoroughly endorse that. There was really no necessity for it. As in the case mentioned, a slight cant brought one well foul of the other, and if two outer wells were sunk first, then there was always a difficulty in getting in another one between them. With regard to the Portland cement, it was tested as it came out, in the chief engineer's workshop. It was also tested before it went up country, and again when it arrived. The proper proportions to be used in making concrete with it were carefully ascertained. They had always found a difficulty in dredging silt. Mr. Walton in his Paper on the Benares bridge, remarked that he used a chisel made of two rails bolted together, which he dropped into the silt so as to break it up, and then removed it by dredging. Unless this was done, the dredger merely scraped the surface and came up empty; it would not bite into it. They also found that if a small boulder or pebble got between the jaws of the dredger, it let all the silt go out, and he had seen dredger after dredger come out without there being half a cubic foot of material removed. The Author had spoken of continuing cylinders to their full height with a diameter of 12 feet, which he said was an advantage. Of course an engineer always liked a margin; but large wells reduced the waterway, and that was the reason, he believed, for the design. Speaking of dynamite, he thought it was a very dangerous experiment, and one which he never would have approved, to attempt to blow up a boulder under the cutting-edge with dynamite, and he was not at all surprised to hear that the cylinder was blown out. Dynamite had been successfully used in that and other bridges by putting a charge below the bottom of the cylinder into the pit excavated by the grab or dredger and exploding it there. In that case it did not do the slightest harm, but caused a trembling motion of the earth all round, and the cylinder generally went down at once. Removing boulders was always a very slow operation, but in dealing with Indian rivers, they could never feel safe until the cylinder rested on the rock. The Author had stated that the bed of boulders was 14 to 22 feet thick under the piers, but 50 or 100 feet further up the river it might be only 2 feet deep. It was frequently found that they were thrown up in big shoals in the bed of the river, and a change in the position of the bridge might alter the circumstances considerably. The Chittravati bridge had been constructed Mr. Robinson.

Mr. Robinson. very cheaply, as Mr. Hayter had explained, and he did not think they could have chosen a better man than the Author.

Sir John Coode. Sir JOHN COODE, President, asked whether any conclusion had been drawn as to what would be the proper distance between the cylinders; of course it would vary in different soils.

Mr. Robinson. Mr. ROBINSON said he should not hesitate to place them 3 feet apart; 3 feet between two cylinders was not much.

Sir Bradford Leslie. Sir BRADFORD LESLIE said that the observations he had to make about the Chittravati bridge, were chiefly with reference to the points in which the design differed from that of similar work carried out in the Bengal Presidency. The Paper was very interesting, as affording details of the difficulties met with in cylinder-sinking through varying strata, especially through the beds of large boulders, overlying the rock. The trouble occasioned by boulders under the cutting-edge was very clearly explained; either they had to be dragged into the cylinders, which generally resulted in an inrush of sand, or the projecting portion of the boulder had to be removed by blasting at the risk of damaging the cylinders. This indicated one great advantage of the adoption of single-well piers. A well or cylinder of 17 feet diameter, with the same area as two cylinders of 12-foot diameter, would have a perimeter of 54 feet only against 75 feet for the two 12-foot cylinders, thus reducing the length of cutting-edge liable to come in contact with the boulders by 40 per cent. The frictional resistance to sinking would also be lessened in the same ratio. The weight of the single 17-foot well would be equal to that of the two 12-foot wells, while the area of skin-surface exposed to frictional resistance in sinking would be diminished by 40 per cent. In deep sinking, moreover, a well of large diameter was much more easily kept upright than a small one. Where they could be pitched in the dry bed of the river, a wrought-iron curb at the bottom connected with the well by vertical ties and diaphragms built into the brickwork, as was done in the north abutment of the Chittravati bridge, was generally found to be sufficient for wells of large diameter. For wells of small diameter in proportion to the depth to be sunk, and especially in cases where it might be necessary to have recourse to the pneumatic process, a complete iron cylinder extending the full height of the pier was generally adopted, as in the Chittravati bridge. The bridge carrying the Bengal Nagpur Railway over the Damoodah river, consisted of ten spans of 200 feet each, and the piers were built on single 26-foot brick wells, without any external iron

cylinders. These wells had been sunk to a depth of 70 or 80 feet into the bed of the river, generally on to the rock. It would be very interesting to have an account of the construction of this bridge, with particulars of the well-sinking for comparison with the new Chittravati bridge. It was probable, however, that the cheapest mode of bridging some of these wide Indian rivers that were dry or nearly so for more than half the year, and where there was no navigation, was by short spans carried above the flood-level by piers sunk a comparatively short distance into the river-bed, which should be protected from scour by a sunken causeway or weir between and around the piers. Everything would depend upon the stability of this sunken causeway, but engineers had now no difficulty in making weirs for irrigation purposes across the largest rivers, and the experience of properly floored flood-openings subject to the full strength of the flood-spill of the Ganges in Eastern Bengal, showed that such bridges would be perfectly reliable. It was a question whether the old Chittravati bridge might not have been protected by a causeway of rubble-stone deposited at a depth of say 10 feet below flood-level, and if the girders were too weak for the modern locomotives, being plate-girders, intermediate piers might have been placed. The greatest credit was due to the engineer for the execution of an immense amount of difficult foundation-work, and girder-erection in a very short space of time, and their best thanks were due to the Author for the record he had given them of the difficulties experienced in sinking through boulders, and the valuable data as to side-friction at various depths below the surface. Sir Bradford Leslie.

Sir Douglas Fox said they were much indebted to the Author for the account which he had given them of the difficulties he met with in sinking these cylinder piers. Engineers who had had to deal with a foundation of that kind could appreciate those difficulties, and there was one point particularly in the Paper to which too much importance could not be attached in practice, namely the statement as to the great uncertainty of borings. They were tempted to rely a great deal too much upon borings, and certainly his experience was that they were the most deceptive things that they could possibly attempt to trust to. An instance of this kind was recorded in the Minutes of Proceedings.[1] Careful borings were taken across the River Esk, near Whitby, and showed soft silt right down to the bed rock. When they came to sink the Sir Douglas Fox.

[1] Minutes of Proceedings Inst. C.E., vol. lxxxvi. p. 304.

Sir Douglas Fox. cylinders it was found that they could not get them below even half the depth; they all refused to move any further. On examination it was discovered that there was about halfway down a submerged forest of trees lying horizontally interlaced one with the other, and that the borings had in every case gone between the trees down to the bed rock. They had just the same trouble with the cylinders as had been referred to by Mr. Hayter, the timbers having to be dragged out from beneath the cutting edge. Dynamite was employed to some extent, and altogether it was a very expensive and troublesome process. In another case, where the borings showed good stiff clay, the actual material proved to be such soft silt that cylinders were sunk to a depth of 50 feet with little more than their own weight. He wished to bear testimony to the excellent effect of using foundations consisting of brick wells, in which plan they were following the ancient practice of the natives of India who had been accustomed for many years to sink these brick wells by divers. By using the wrought-iron cutting-edge and a brick well on the top of that, a most substantial pier could be carried to a considerable depth. In South India it was found important, as had been mentioned by Sir Bradford Leslie, to floor the bridges. A great deal was sometimes learnt by misfortune, and they had an example in South India which showed what a thoroughly efficient foundation such wells, carrying masonry piers combined with a floor would make. They had there a bridge rather larger than the one in question, with seven spans of 150 feet, which was suddenly assailed by an unprecedented flood, caused by the bursting of a large irrigation dam just above, bringing down on it a forest of trees. The bridge was constructed with lattice-girders, and if it had not been for the trees nothing would have happened. The flood rose much above its normal height, and reached a level never known before. It came up practically to the top of the girders, and gradually the trees piled themselves in a dam against the sides. What he wished to point out was this, that though the whole of those seven spans of 150 feet were swept away into the bed of the river, the piers stood perfectly sound and good, so that in order to repair the bridge they simply raised the height of the piers sufficiently to meet such an abnormal flood, and replaced the girders upon them. It was not only an economical mode of construction, but was thoroughly efficient. He agreed with what had been said as to the importance of leaving plenty of room between the cylinders for canting. He hoped that a Paper would be brought before the Institution, referring to the very large cylinder sunk by his brother, Mr. Francis Fox,

M. Inst. C.E., in connection with the River Dee, in which case it was found very important to provide against canting, because they had a difficulty with the sand. There was no reason why the space referred to by Mr. Robinson of 3 feet between the cylinders should in an ordinary case cause any special difficulty, and he thought it would be unwise to attempt to place cylinders in a river of that kind, as closely as they could place them in the River Thames. In the case of the Victoria (Pimlico) and other bridges the cylinders were placed close to one another, but in the London Clay they could be controlled very much better than they could in an Indian river. Sir Douglas Fox.

Mr. J. Wolfe Barry asked if the Author could supplement his Paper by some further particulars as to the circumstance he mentioned of there being 8 feet of slurry found after a thickness of 30 feet of concrete had been deposited under water. That seemed very extraordinary, and if the Author made any analysis of the slurry to determine its composition, so as to see whether it was cement which was not set and had been washed out—or partly cement and partly dirt—it would be instructive to engineers who had to deposit concrete under water, and were never absolutely certain what happened with it, to have that information. With regard to what had been said by Sir Bradford Leslie as to the desirability of affording some surface protection to the piers, he would draw attention to the fact that one of them, No. 11, appeared to be resting upon a foundation which was not thought good enough for the rest of the bridge. It would seem prudent, therefore, to take some precaution for shielding that pier from the action of the river if any erosion of the bed should take place. Mr. Barry.

Mr. W. R. Robinson said it had always been the intention as far as he knew to throw stone round all those piers, but he had not heard if it was yet done. In the original plan there was a flooring, and he thought it had been put in. Mr. Robinson.

Mr. G. F. Deacon said it would be useful to hear the opinion of others as to the employment of dynamite for the purpose of causing vibration of the ground, and thus increasing the tendency of large cylinders to sink. His own experience had not been very satisfactory. When a cylinder was forced down by simple loading, the strata were disturbed to the slightest possible extent; but the explosion of the dynamite shook the ground, and thus, while causing the cylinders to descend with a smaller load, increased the tendency of the soil to run in below the cutting-edge. The resistance to vertical motion of the cylinders was generally different at different parts of the cutting-edge, and this, when the run of the ground Mr. Deacon.

Mr. Deacon. and sinking of the cylinders took place simultaneously, often caused serious canting. The use of dynamite fired well below the cylinders was an expedient which might succeed when loading and excavating failed, but was only to be applied with great caution. Like Mr. Barry, he had been much struck by the statement concerning the quantity of slurry found upon the concrete in one of the piers. More information respecting this was desirable. It seemed incredible that the whole of that 8 feet of slurry should have been the product of the 30 feet of concrete beneath it.

Sir John Coode. Sir JOHN COODE, President, said he agreed with Mr. Barry and Mr. Deacon that the existence of the 8 feet of slurry was very extraordinary, and more so when taken in connection with the fact that the concrete below it was set quite hard. The Author would, no doubt, be able to give them further explanation on the subject.

Mr. Shelford. Mr. W. SHELFORD said that in his own experience some of the hardest concrete he had ever seen had been so honeycombed that it would admit of the passage of the silt from the bed of the river right through it, and he thought that the extraordinary thickness of the slurry found on the top of the concrete in the cylinder might be accounted for in that way. With regard to the observations which had been made about the sinking of cylinders by means of grabs, a great deal depended upon the form of the grab-scoop. He had himself found that where grabs would not penetrate the bottom at all, when a tooth was added on the outside of the scoop it enabled it to enter and do its work. Very much depended certainly upon the material to be encountered in sinking the cylinders. The cutting-edge of the grab must be of a form suited to the material intended to be removed. Although for the purposes of sinking it might be cheaper to have the lower part of the cylinder smaller in diameter than the upper part, it caused great inconvenience when grabs were used, but, on the other hand, if the cylinder was of the same diameter all the way up, it interfered with the waterway of the river. He entirely agreed with what had been said by Sir Bradford Leslie as to the practicability, in such a river as the Chittravati, of protecting the piers from scour by the construction of a weir. He had lately seen in the Argentine Republic a bridge about a quarter of a mile long, with spans of 10 or 11 metres, carrying a railway across a river of a very similar description, the piers being screw-piles. The bed of the river was sand, which was usually dry, so that it was the easiest thing possible to erect the bridge; and no doubt if at any time it gave trouble the simplest way to keep it in position would be to

protect the sand from being scoured away by the floods. He had himself proved the practicability of that plan, having made a weir across a river with a silty bed in the Fen district, at a very small cost, which effectually prevented any scour. Mr. Hayter had not said anything about the design of the girders, and Mr. Shelford would like to ask why the depth had been fixed in such a way that it was necessary to raise the transverse girders overhead 10 inches above the main girders in order to give headway to the train underneath. He did not see why the girders should not have been made of a greater depth, and, in fact, they would have been cheaper if they had been deeper. The American practice, as they were aware, was to make the girders of much greater depth proportionately than these, and they had found out by experience that that was the most economical system; and he had proved it to be so in a Paper read before the British Association in 1886. He would also like to ask why the cross-girders were attached to the side of the bottom boom, and not suspended underneath in the way which was now usual. The common practice was to carry the web-plate of the vertical members through the bottom boom, and to attach the girders to it in such a manner that they formed part of it, so that there should be no undue strain on the rivets, but only a sheering stress. He would also ask why the girders were made of iron and not steel, which he thought a more reliable material. Mr. Shelford.

Mr. GEORGE BERKLEY, Vice-President, said that some of the cylinders, 11 feet in diameter, of the Bookree bridge, on the Great Indian Peninsula Railway, had cracked in or near the bottom, although there was no apparent fault in the metal. When a cylinder was sunk through material containing boulders, or rocks, one part of the cutting-edge might rest upon them, whilst the other had no such support, and when a weight of some 300 to 400 tons was put on the top of a cylinder, sunk 50 or 60 feet into the soil, and arrested in that manner by the obstructive material, there was very great risk that the cast-iron would crack. It did crack in the case referred to. He thought it would be desirable to pull the cylinder down as well as push it, so as to relieve the compressive strain. Mr. Berkley.

Mr. ROBERT RIDDELL said, in 1884 he was engaged as resident engineer in the erection of a girder-bridge with cylinder-piers across the Bookree River on the Great Indian Peninsula Railway from the designs of Mr. Berkley. The conditions were somewhat similar to those of the Chittravati bridge. The river was subject to floods rising as much as 20 feet in a few hours during the Mr. Riddell.

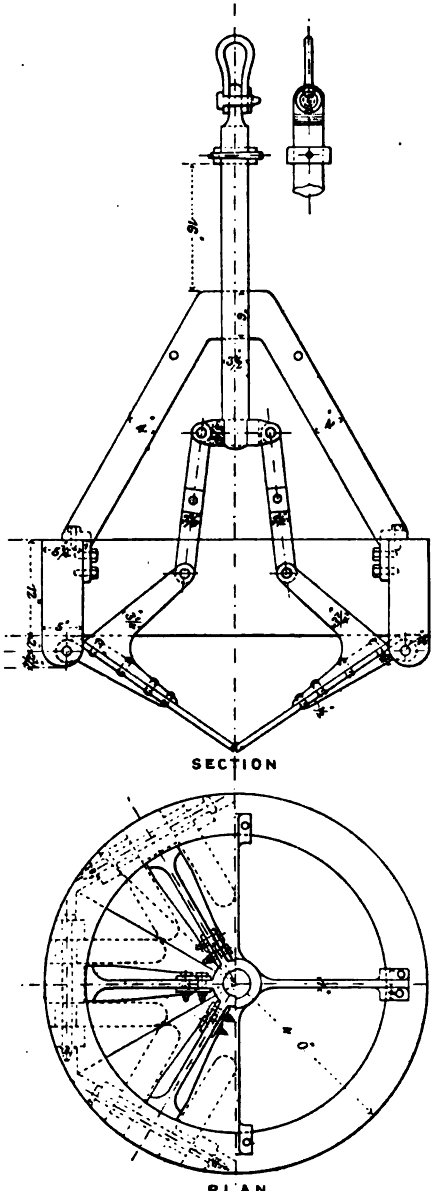
Mr. Riddell. monsoon. The strata through which the cylinders were sunk consisted of moorum with large stones, conglomerate of kunkur, moorum, and gravel, and impacted sand and moorum. (Moorum was supposed to be decayed trap-rock; it was like a hard clay or marl.) On the last of these the cylinders were founded at a depth of about 36 feet below the bed of the river. Each pier consisted of two cast-iron cylinders 11 feet in diameter below the bed of the river, and reduced by a tapering ring to a diameter of 9 feet above that level. The superstructure was for two lines of railway, and the spans were 109 feet from centre to centre of the piers. The method of sinking was similar to that described in the case of the Chittravati bridge, namely, by placing a stack of rails on the top of the cylinders. From the results, he thought there was no doubt it would have been better to have put some of the weight inside the cylinder by building up a ring of brickwork, or concrete, resting on a ledge. That would have reduced the chance of fracture, which did happen in a slight degree, and also the cost of sinking, and of removing and re-stacking the rails every time a new ring had to be added, which was very considerable. In excavating hard stuff in the cylinders below water it was often found that the Bull dredgers, which were used, would not sink through it. He therefore employed a long vertical iron rake, the shaft of which was made of old rails bolted together, pointed at the end, which sunk into the ground in the centre of the cylinder. About 3 feet above the bottom a cross-piece armed with strong steel prongs was bolted on, and the rake was revolved by capstan-bars from the top of the stack of rails. That loosened the hard clay, impacted gravel, and conglomerate of moorum, kunkur and gravel, and enabled the dredger to bring up the stuff. They met with a good many large stones and boulders, which had to be broken by the divers with hammer and bar, and then sent up in buckets to the top. There was no difficulty after the boulders, debris, and conglomerate had been broken and removed, in bringing up the rest. The excavation was always kept down below the level of the cutting-edge, except where a run took place, when the cutting-edge sank deeply in the ground: the maximum run was about 5 feet. The average final weight placed on the cylinders was 335 tons, the minimum being 333 tons, and the maximum 375 tons. When the cylinders reached the required depth a plug of cement-concrete about 8 feet thick was let down in hopper-boxes through the water. That was allowed sufficient time to set—sometimes four days, sometimes a week, and the cylinder was then pumped dry. On the top of the

concrete about 3 or 4 inches of white sludge was found, which he believed to be composed of fine particles of the lime from the cement; it had no setting property whatever. The cylinder being dry, the cement was let down in hopper-boxes, disturbed as little as possible, and never rammed. Experience taught him that cement-concrete of good material in proper proportions, and mixed with the right quantity of water, did not require ramming, and indeed he thought ramming was injurious. Possibly the large quantity of sludge of which the Author had spoken—8 feet of sludge to 30 feet of concrete—was due to the concrete being unduly agitated in the water. Mr. Riddell.

Mr. J. R. MOSSE said, with reference to the remarks of Sir Douglas Fox, that he knew of two instances in which foundations had not proved to be what was anticipated, without any blame at all being attributable to the engineers. The first of these occurred on the Inter-Colonial Railway of Canada, of which Mr. Sandford Fleming was engineer, about the year 1870. That railway, in going through New Brunswick, crossed a large tidal river at Miramichi by several spans of 220 feet each; the depth from high-water to the sand being 30 feet. There was 10 feet of sand, then a bed of gravel 7 feet thick, and below the gravel 50 feet of silt. There was great discussion as to whether the foundations should be laid upon the 7 feet of gravel, or whether they should go down to the rock through the silt, which would have made the depth of the foundation from high-water level 97 feet. After a good deal of consideration, Mr. Sandford Fleming determined to found upon the bed of gravel. The piers were of heavy ashlar work, with large cut-waters to resist the pressure of the ice. They were put down in timber caissons 60 feet by 30 feet, and so much difficulty was experienced in getting the foundations down to that bed of gravel, that 1,416 cubic yards of material were removed from Pier No. 10, and 356 cubic yards of water were pumped up for every cubic yard of excavation. He did not know whether other engineers had had similar experience, but he thought that 356 cubic yards of water for 1 cubic yard of material constituted an enormous difficulty in getting in foundations. The piers were of solid masonry founded upon this bed of gravel over 50 feet of silt. They were loaded for six months with from 500 to 600 tons of rails. They all sank somewhat, the minimum being about 6 inches, and the maximum 13 inches, but without cracks and with only a gradual settlement of the masonry. It proved very successful, and to the best of his knowledge no flaw had ever occurred. A similar Mr. Mosse.

Mr. Mosse.

Fig. 2.



CEYLON GOVERNMENT RAILWAY EXCAVATOR.
Scale ¼ inch = 1 foot.

case occurred in Ceylon, where a large river at Kalutara was crossed by a bridge built in 1876 with twelve spans of 100 feet. There was rock on the ledge of the bank, and every indication that there would be rock in the bed of the river. The depth of the water was 35 feet, but the bottom proved to be only a layer of gravel 2 or 3 feet thick, and afterwards came some 30 feet of sand. They had to get down to the rock from 60 to 70 feet below the water. The cylinders were small, 6 feet in diameter, so that no elaborate plant was needed. They had to use the best native labour they could get, and therefore something very simple had to be adopted. All kinds of machines already mentioned for getting out foundations in cylinders were tried, including the ordinary jham and sand-pump, Bull's dredger, Molesworth's dredger, Ives' excavator; they all worked well in the sand, but when they came to clay great difficulty was found. The best implement for the clay was what was called the helical excavator, invented by Mr. E. W. Stoney, the Author of the Paper. That

was found effectual, but at great depths it gave a good deal of trouble in working the vertical rods. Boulders were removed, and rock excavation done by divers wearing Heinke's dresses. In 1880 a large bridge was built over the Kelani River, and the dredger used was designed by the resident engineer of the railway, Mr. Edward Strong, who had been in Ceylon for many years. It consisted of a cylinder, *Fig. 2*, 4 feet in diameter, the vertical part of which was about 2 feet in depth; the bottom was nearly semi-circular, divided into six parts, and made almost to fit as a hemisphere. The triangular pieces were pointed and sharp. It was weighted heavily, and went down so that the sharp points penetrated the clay, and when it was drawn up it raised the material with considerable effect. As far as his experience went, it was the best dredger he had seen. **Mr. Mosse.**

Mr. T. Wrightson said he had never known a bridge go through any works so rapidly as the New Chittravati bridge had done. The reason was that the details were so thoroughly well worked out beforehand, in Westminster. That was not always the case, and therefore the manufacturers did not wish to take any credit to themselves for that particular part of the work. With reference to what had been said by Mr. Shelford with regard to increasing the depth of the girder, possibly some saving might have been effected by doing so, but he did not think it would have been very great. But if Mr. Hayter had designed the girder of a greater depth, he would have been able to get the top boom so much deeper that he would have had rivet surface enough for the attachment of the diagonals direct to the top boom, and that would have been a considerable saving in the weight, as the separate joint-plates would have been saved. With regard to the conclusion come to by the Author upon the question of cylinder-sinking, he had done good service in recording his experience. He had tabulated about one hundred and forty-five extremely interesting observations, evidently made with considerable care. And the average of these gave a skin-friction equivalent to just under 2 cwt. per square foot, the maximum running up to 3·52, and the minimum being 0·63. In designing cylinders for supporting a bridge it was often difficult to get the necessary information by which to decide the depth. They might trust largely to the skin-friction; they might trust entirely to support at the base of the cylinder, or the bridge might be designed taking both into account. Any information upon the question of skin-friction must be exceedingly useful to those who had **Mr. Wrightson.**

Mr. Wrightson. to design bridges, and therefore this was perhaps the most valuable part of the Paper. With regard to skin-friction, it would not do to depend upon too low a coefficient. He had under observation some two or three years ago the case of two bridges in Devonshire, one across the Tavy and the other across the Laira, and in those bridges the cylinders went down into the mud 70 or 80 feet in the deepest part. It might be within the knowledge of the older members of the Institution that one of the first works which the elder Rendel carried out, and one of the things that brought him prominently before the public, was the building of the bridge across the Laira, and when his firm took the contract for a modern bridge within a few feet of that structure, he consulted Mr. Rendel's Paper[1] with great interest to see what kind of foundation they would have to deal with. The design of the later work was made by Messrs. Galbraith and Church. When the cylinders were sunk into the river they had to weight them down, and a very curious thing happened. In many cases the weight had been on, sometimes for a considerable time, when the cylinders suddenly sank, for 10, 20, 30, and even as much as 40 feet. In the case of the Laira there was one that went as far as 42 feet in a few seconds, and in the Tavy there was one within a foot of that figure. It might be easily imagined that this caused some alarm to the men; in fact, in the case of the first cylinder which sank, the men had just gone to their breakfast, and they had not been out more than two or three minutes when it shot away in that extraordinary manner. After a time, however, they became quite accustomed to the phenomenon, and prepared themselves for it. The majority of the cylinders in both bridges sank in this way. He had made an estimate of the amount of skin-friction which was overcome at the time when these runs occurred. In one case in the Laira bridge, taking the weight of cylinder plus the weight of rail with which it was loaded, and assuming it to act over the whole of the subterranean part, the resistance amounted to 2·1 cwt.; in another case to 2·5 cwt.; and in another to 2·8. In the Tavy bridge cylinders, most of which ran away, the skin-friction was from 2·3 cwt. to 2 cwt., so that these figures approximately corresponded with those given by the Author. Of course the value of the skin-friction varied in different circumstances; but it would be an interesting contribution to their

[1] Transactions Inst. C.E., vol. i. p. 99.

knowledge if some one could ascertain what it was in the many cases of cylinder-sinking which had been recorded. Mr. Wrightson.

Mr. E. W. Young said that the most important point for consideration in the discussion on the erection of the Sukkur bridge was the comparative merit of two diverse systems of erection. In the large bridges which were now made the parts were very often built up in pieces, and it was necessary to adopt that system of erection in many cases, but it was not so satisfactory in some respects as building up each member complete, adjusting it to its exact length, and so getting it into position. The system of building-up, especially where temperature came into play very much, was productive of error. One could understand that the difficulty of putting up a strut, raking in two directions like No. III, from such a small base, and getting it to the right position at the top must be very great. In confirmation of this view he observed that the Author spoke of an error on the completion of No. III strut, where "the span for the horizontal tie proved to be $\frac{5}{8}$ inch too much on one side, and $1\frac{1}{4}$ inch too much on the other." That was comparatively a small error, but it must be very objectionable to have those differences of length. He should have preferred to build the strut in one piece, haul it up, and drop the end of a temporary tie into a V-shaped jaw at the upper end of the strut, getting it into position in that way. He hoped to hear from members who were qualified to speak on the matter their experience as to which was the best method of erecting structures of that kind, whether by building them up piecemeal and riveting them together, or taking each member as a single piece and hauling it into position. The Author had stated that "a piece of the strut, generally about 30 feet long and weighing 5 tons, was lifted into its place, and held up by a $1\frac{1}{2}$-inch wire-rope (7 tons breaking strain)." That was in his judgment working rather too close to the limit of the strength of the rope. He should be very sorry to put 5 tons on a rope with a breaking strain of only 7 tons. The method of hauling by means of winches worked by an endless rope from below was very ingenious and useful for that mode of erection, and the Author deserved great praise for the ability he had shown. Mr. Young.

Mr. Ewing Matheson said the description of the Sukkur bridge, as he gathered from the Paper, was confined entirely to its erection. That was a little to be regretted, as there might be something to say with regard to the design of the bridge. In describing the erection of it the Author gave some figures which Mr. Matheson.

Mr. Matheson. really involved the question of design. It would be interesting if a comparison could be made between the superstructure of that bridge and that of the Forth bridge, inasmuch as both had large cantilever spans. They could hardly think that the Sukkur bridge was more difficult to erect than the Forth bridge, but it appeared to have cost more per ton. Taking the figures given by the Author he thought it was not quite right to put down the cost of the erection merely as 570,000 rupees. Of the incidental expenses which appertained to erection, such as workshops, sidings, plant, boat-service, and so on, ironwork ought to bear its share, and if that were the case it seemed to produce a very high price per ton for the erection. It would be interesting if the Author could ascertain if the price of the ironwork delivered at the site, which seemed to be rather extraordinary, was due to the peculiar manner of dealing with it at the beginning. It was all put together in London, and it was a question how much was saved thereby in the erection of the bridge at the site.[1] When they came to set it up, probably they found considerable advantage from the fact that the bridge had been already once erected. Such a proceeding was, however, he thought, unprecedented.

Sir Bradford Leslie. Sir BRADFORD LESLIE said that the mode of erection of the Sukkur bridge appeared to be admirable, and to have been well carried out, so that there was very little to be said on that subject. As to the design of the bridge he wished to make a few observations, seeing that the difficulty of erection had been affected by it. The cantilevers seemed to have been arranged almost without reference to this question. He did not know whether the engineer by whom the bridge was to be erected was consulted, but if that course had been adopted he should have expected that the design would have been much improved. The main strut No. III, weighing 240 tons, was a most difficult member to erect, being inclined not only longitudinally in the direction of the bridge but transversely. No doubt there were good reasons for the adoption of a strut in that case, one probably being that it would impart stiffness to resist wind-pressure, but the same object could have been attained if the vertical end-pillar A had been strengthened; in fact it might have taken the form of a cast-iron standard, and being erected on shore would have been straightforward work. A tie from point A to the foot of No. IV

[1] An account of the temporary erection of the Sukkur Cantilever Bridge at the Works of Messrs. Westwood, Baillie and Co., Poplar, appeared in "Engineering," March 9th, 1888.

Sir Bradford Leslie.

vertical might then have been substituted for strut No. III, and such a tie would have been much lighter and easier of erection. That again would have reduced the strain on the top horizontal tie AB, which might then have been less heavy, and therefore more readily put in place. The erection of the top tie was a very difficult matter, as would be seen by reference to the diagrams, a special kind of suspension bridge having been constructed for the purpose. It was true that the weight of No. IV vertical member would have been increased by such a modification of the design, but being vertical in the transverse plane, the difficulty of erection would not have been greatly affected by a little increase of weight. The end pillars on the abutments, the main strut No. III, and the other minor struts and pillars, being reduced almost to a point at the ends, it appeared that the superior strength of pillars fixed at the ends was practically sacrificed. At the point B the pillars appeared to shrink specially to avoid contact one with another instead of becoming united as soon as possible, and the material in those struts and pillars was used to little better advantage than it would have been in pin-connected columns. If pin-connections had been adopted much of the difficulty and extreme care necessary to avoid straining the joints would have been obviated, and a considerable saving of time would have been effected. Riveted connections having been decided upon it would have simplified both the construction and the erection to have made the struts and pillars with parallel sides, instead of spindle-shaped. This would have obviated the delay experienced in rigging stages for the men to work on, and would have greatly stiffened the structure, as it would have enabled the struts and pillars to be more rigidly connected by the increased area at their ends. The system adopted by Mr. Robertson, especially the precautions taken for the accurate building up of the main raking-strut No. III, and the suspended staging for the erection of the main horizontal tie at an elevation of 170 feet, depending at the outer end on the unstable head of the main strut, was a skilful and ingenious manner of accomplishing a difficult task. The accuracy with which the calculations had been made of the allowances for the extension of the back guys due to the weight of the cantilevers, and complicated by variations of temperature, was very remarkable, and the use of the adjustable steel-wire spans for carrying the lighter members of the cantilevers into position, and also the temporary bow-string bridge for the erection of the central girders were equally admirable. It appeared to him difficult to suggest any improvement on the mode of erection adopted. Its safety and

Sir Bradford Leslie. simplicity, and the small amount of special plant required, were some of its best features. Before deciding on the general design of a bridge, it was to be supposed that a comparison was made with other designs which were feasible. Where the entire length of a cantilever on both sides of the fulcrum or central support could be turned to account for bridging a large span, it was beyond all question the best type of construction, but in a single-span bridge the proper application of the cantilever principle would seem to be that it should be used as a temporary means of erecting some more appropriate type of bridge. The anchoring of the cantilevers of the Lansdowne bridge required a large amount of steel-work behind the abutments—some 600 tons—which would have been saved by the adoption of a trussed bridge, like Brunel's Saltash bridge over the Tamar. A structure of this type, including special wind-bracing, would have weighed roughly 2,600 tons and could have been conveniently erected by using half the chains temporarily as back guys for the standards on each side of the river, and the other half to provide a temporary inverted bow-string girder (similar to that used by Mr. Robertson for the centre girders) for the erection of the permanent structure. When that was complete, the links temporarily used as back guys, would have been removed, and fixed in their proper positions in the bridge. They might first have been suspended independently, and their share of the weight brought on to them by hydraulic pressure. In that way a bridge of the Saltash type might have been very easily erected. It was, however, impossible to look at the section of the river, with the limestone rock rising on both sides available to resist horizontal thrust as well as vertical pressure, without feeling that the site was favourable for the consideration of some form of arched bridge. By an arched bridge, he understood one in which the material of the longitudinal ribs was subject to compression only, varying within certain limits according to the position of the moving load. In such a structure there would be a rise and fall at the centre, owing to differences of temperature; but otherwise any required degree of stiffness could be given with a weight of metal not exceeding half of that of the cantilever-bridge. If properly designed to facilitate erection, it could hardly be doubted that such a bridge could have been successfully placed in position, especially by an engineer like Mr. Robertson. A skeleton arch to serve as a staging for the complete structure of which its material would ultimately form an integral part, might have been built on the side of the river, floated down and erected, or it might have been built in the

centre line of the railway, and launched forward somewhat in the manner done with the girders of the Jubilee bridge. Whatever method of erection was adopted, no doubt an arched bridge, including wind-stays and bracing, could have been built for half the cost of the cantilever-bridge, by taking advantage of the rock abutments. He was aware that the arched form was out of fashion just now; but for large spans, where the abutments were not too expensive, it would be found to be more economical than any other type, provided that the system of erection was considered in making the design. Sir Bradford Leslie.

Mr. WILLIAM PARSEY wished to offer some remarks with regard to the method of constructing the Sukkur bridge. He was engaged by Messrs. Westwood, Baillie and Co., and had the entire charge of the erection of the work in their yard. The temporary erection was carried out on quite a different system to the final, because in the first case, the whole structure had to be supported upon scaffolding, whereas in the final erection, having been already put together once, it all came easily into place. The scaffolding employed in the yard had to carry the entire weight of the bridge, and it was necessary that it should be perfectly rigid. There was no movement at all except in strut No. III, which lent over at the top end $\frac{1}{2}$ or $\frac{3}{4}$ inch. The mode adopted for the final erection by Mr. Robertson appeared to have been as perfect and as good as skill could contrive. There was only one other way in which it might have been done, and that was to have carried wire-ropes across, so as to form a wire-ropeway, and to have used a travelling carriage, dropping the weight down from that, which would have amounted to much the same thing. It had been asked whether it was advisable under such circumstances to erect a bridge of that class in England. Upon that subject his impression was that it was perfectly necessary that the work should have been put together in this country. It was the universal practice with bridges of 100 or 200 or 300-foot spans to put them together in the contractor's yard before sending them out, and this bridge being of a novel construction and very complicated, it was all the more necessary that it should be treated in the same way. Reference had been made to the testing of the lengths of the different members. All the pieces were laid down in the contractor's yard and very carefully tested before they were erected on the temporary scaffold. They went together perfectly, and in no instance did they have to shift or alter a single piece, and he thought that the contractors were entitled to considerable credit for the care and skill exercised on that part of the work. The Mr. Parsey.

Mr. Parsey. cost of erection in this country was between £3 and £4 a ton. He estimated it at £5 a ton before starting with the work. The total cost at the finish was between £12,000 and £15,000 for the 3,000 tons, including scaffolding, or nearly £5 a ton, and when the scaffolding was taken down, the timber, which cost over £7000 was sold, and the contractors got £2000 or £3000 back, so that altogether the actual cost of erection could not be put at more than about £3 10*s*. a ton. As to the mode of keeping the centre-lines and the direction of the members, it was all set out in the yard to centre lines, arranged with the theodolite from one end to the other, and everything worked from the centres. At the final erection that mode could not be very well carried out; and therefore, in dealing with the principal members, marks were made, and lines drawn so that the levels and widths could be checked. These lines and marks were put on the steel and iron-work in the yard by erecting temporary stages at various points. He first of all got the widths from the centre-line on each side, put the theodolite down, then ranged the line up to cut the different parts of the structure, which were marked with paint lines and centre-punch holes, and these were the marks by which Mr. Robertson finally erected it. With regard to the lifting-gear, that was all designed in England by Mr. Robertson. It seemed to have answered very well indeed.

Mr. Read. Mr. R. John G. Read said he had been very much interested in reading the account of the erection of these bridges. There were some points in the design he should like to speak upon. He would ask what was the idea of putting the last strut in the reverse direction on the nose of the cantilever. He thought the strut put in its normal position following the previous ones would have been at too flat an angle, and therefore it had been superseded by a tie in the opposite direction. He should be glad of some information as to the proportion of the length of the central girder to that of the arms of the cantilever. Perhaps the engineer of the Forth bridge might be able to tell them how that was arrived at. He thought it was found by trial in this way:—given a certain length of span, calculating what would be the weight of the whole bridge with the centre span of an assumed length, and the cantilever arms following it. In a shorter span cantilever-bridge due regard must be taken to the moving load, because if the cantilever arms were made long in proportion to the centre span the deflection from the moving load would be greater in comparison to the weight of the structure in the small than in the large spans, and therefore the nose of the

cantilever would be deflected more. That was experienced in the Niagara River bridge where they found great deflection with trains running at high speeds, whereas if the centre girder was made longer in those small spans it would tend to reduce the deflection. He asked what was the deflection of the bridge with the ordinary traffic. It was, he believed, stated in some of the Indian papers that, although trains had been running over it at high speeds and it appeared to be rigid, or nearly so, after Lord Reay had declared it open, a crowd of natives rushed to go across it and set up such a vibration that they had to be ordered off, and the bridge was practically stopped for foot-traffic until it had been stiffened by some cross-bracing. He would be glad to know if that was true, and, if so, what bracing had been put in, and whether it had acted successfully under a similar strain. Looking at the general design he could not help being struck with the great difference between it and all existing cantilevers with which he was acquainted. Most of the bridges now built were made with two piers at least so as to give the cantilever a balancing arm on each side towards the shore end. In the case of the Sukkur bridge it seemed impossible to have built a pier in the river, and therefore there was a wide span to be got over with practically a flat bank on each side, and supposing a cantilever to be adopted he did not see what else could be done than to anchor back the projecting arms in the way that had been done. That was not altogether satisfactory. It seemed that the centre of gravity of the arm of the cantilever was hanging over the water, instead of, as in most bridges—in fact in all that were now built, coming either over the pier or at the back. In the Forth bridge, in which the arms were equal, it would go over the piers. In the Hooghly bridge, support was afforded by two piers at wide distances apart, and therefore the centre of gravity of the whole came well within the middle of the piers. In the Niagara River bridge, the shore-arms were made heavier than the river-arms, and the centre of gravity was thrown back behind the supports, which helped it to sustain the extra weight of the centre girder on the nose of the cantilevers. In the Forth bridge the extra weight of the centre girder was counterbalanced by the heavy load put on at the end of the shore-arm to keep it down, and probably in that way it had been found by experience to be more economical to add that extra dead weight than to extend the length of the arm; the cost of building out a long cantilever-arm was more than that of putting on the dead weight and erecting the extra pier on the shore. It Mr. Read.

Mr. Read. seemed that in the double-armed cantilevers there must be great deflection. The vibrations in cantilever-bridges were of two kinds, varying above and below the normal line, the amplitude of vibration being much greater than in an ordinary girder-bridge. The weight in an ordinary girder-bridge and the deflection were greatest in the middle, and the weight tended to rectify the bridge to its normal condition after the moving load had passed; but in cantilevers the lightest part of the bridge was at the nose of the cantilever where the greatest deflection would take place. When a train was entering on a double-armed cantilever the tendency was to lift the nose of the cantilever in front, and when it came on to the bridge it was tilted the other way, so that there was a vibration up and down at the centre. In the bridge under discussion there could only be a deflection one way, because the load as it came on to the bridge was simply bearing on the abutment—and as it reached the cantilever arm the only tendency was to deflect it downwards. He should be glad of information as to how the bridge behaved under deflection.

Mr. Hayter. Mr. HARRISON HAYTER, Vice-President, said that, in the absence in India of Mr. Stoney, the Author of the Paper on the Chittravati bridge, he would reply to the various points raised in the discussion in connection with that structure. Allusion had been made to the question of protecting the bed of the river and the piers of the Chittravati bridge with stone. If stone-pitching had been introduced under the bridge as well as above and below it, which would have been necessary, and if it could have been kept in place, there might have been no occasion to have sunk the cylinders until they reached solid material. He had gone into the question of the comparative cost of going down to the full depth, and of finishing at a lesser depth and pitching the bed of the river, and he found it unfavourable to the latter plan. During floods the sandy material of the river-bed was subject to the action of scour to a depth of 15 or 20 feet below the surface, and it would have been impossible to have kept stone-pitching in place without pile-work or works of protection both on the up-stream and down-stream side of the bridge, and the cost would have been altogether prohibitory. The same remarks would apply as to the construction of weirs, which had been referred to. As to throwing loose stone around the cylinders, he remarked that the bottom of each of them had a good hold on solid material, and at the top, each pair was well braced together by rigid wrought-iron plating (Plate 8, Figs. 11 to 13). No scour that could take

place could, he believed, affect the stability of the piers; hence it would have been useless to have incurred the great cost of throwing in loose stone around them. It was evident that should any one of them at any time be unduly scoured, loose stone could be placed round that particular pier, but it was not probable that the necessity for it would arise, considering the depth to which the cylinders were sunk and the solid material reached, and there was no reason to provide by anticipation against such an occurrence. He quite concurred in the remarks made by Sir Douglas Fox as to the uncertainty of borings. He had some borings made in connection with an important work, and they indicated that rock would be met with at a certain depth, whilst actual excavation revealed the fact that it was some 20 feet deeper, and he could cite other similar cases. Attention had been drawn by Mr. Barry to the slime or slurry referred to by the Author, which was left over the concrete in the cylinders, and the circumstance had also been noticed by the President and Mr. Deacon. This slurry was formed to a remarkable extent in the case of concrete made with Portland cement obtained from one particular manufacturer, the cement having been supplied by several. Mr. Hayter believed that the occurrence was due to the fact that there was an excess of lime in it, which was not taken up by the silica and alumina, and which being set free, floated to the surface. The material in other respects seemed to have been good, for the Author said it set quite hard. There was great variation in the quantity of lime contained in different Portland cements, the limits ranging perhaps from 55 to 65 per cent. He believed that generally speaking the lime was in excess, and this was to some extent necessary to enable the material to stand the often severe tests to which it was subjected at an early stage after manufacture. He had reduced these tests with advantage, and he got a cement that was stronger after the lapse of time. But lime was not so injurious as magnesia, which also created a slime. It was well known that when concrete was subjected to the action of sea-water entering and leaving it, a deposit of magnesia was formed with most disastrous results, of which he had had considerable experience. Hence the necessity for a chemical as well as a mechanical test. Unfortunately it was not known at present what should be the constituent parts of good Portland cement, but he understood that the subject was being investigated by a competent chemist. When in the possession of reliable data he for one hoped to institute a chemical test as well as a mechanical one in the case of Portland cement. Mr. Shelford asked why Mr. Hayter.

Mr. Hayter. Mr. Hayter had not, in designing the Chittravati bridge, placed the cross-girders underneath the main girders, and this opened up the subject as to the best method of supporting cross-girders. The plan he believed most usually adopted for some years after the introduction of wrought-iron girders, was to rivet the cross-girders underneath the bottom boom or flange of the main girders, so that they depended for their support upon the rivet-heads. But whenever the cross-girders were deflected by a load, it was evident that the effect would first of all be to bring a strain on the row of rivets nearest the centre of the cross-girders, and this row would have to be brought into a considerable state of tension before the next row came into action. In this way the row of rivets nearest the centre line of the cross-girder fastening it to the bottom boom would be strained more than the second row, and so on in succession until the last row furthest removed from the centre line of the girder was reached, which would have little or no strain upon it. This plan, therefore, was not mechanically correct. Further, it was objectionable to depend upon the heads of rivets for support. The same remarks would apply if bolts were used instead of rivets. In the Charing Cross Railway bridge over the River Thames, which he had described in a Paper read at the Institution in 1863,[1] the cross-girders were suspended to the underside of the bottom boom of the main girders by two vertical angle-irons on each side of the bottom boom, riveted to it and continued down so as to embrace the cross-girder on either side, and to which the cross-girders were riveted. In this way the support did not depend upon the heads of the rivets but upon their resistance to shearing, and the rivets on each side of the bottom boom would act together, as they would be over one another, or in the same plane of resistance. An objection to the plan was that the outside faces of the vertical plates of the bottom boom had to be kept flush, so that the suspending angle-irons might be riveted to them, and thus the angle-irons securing the vertical plates of the boom to the bottom horizontal plates could be placed on the inside only. The plan referred to by Mr. Shelford of attaching cross-girders to the underside of the bottom boom of main girders was in every way satisfactory, and no better could be devised, and it effectually united the latter together transversely. In the Chittravati bridge, however, head-way was a consideration. If he had fastened the cross-girders underneath the main girders, the whole of the cylinders and the abutments would have

[1] Minutes of Proceedings Inst. C.E., vol. xxii. p. 512.

to the depth of the cross-girders, which would have increased the cost of the structure. The plan he had adopted was the not unusual one of resting each cross-girder on the bottom horizontal plate of the bottom boom. It took its bearing on the inside bottom angle-iron, was riveted through it and through the bottom horizontal plate and to an angle-iron on the upper edge of the inside vertical plate of the boom (Plate 8, Fig. 2). A diaphragm or filling-piece was inserted at each cross-girder in the trough of the bottom boom, which was strongly attached to it and to the cross-girder. In this way the cross-girder was practically carried through the bottom boom and would bear over its width. This mode of attachment was mechanically correct, and was free from objection, and in fact was the only proper plan to follow in cases where a fixed headway underneath the bridge had to be maintained at a minimum cost. He would give reasons for preferring iron to steel in the case of the Chittravati bridge, as that subject had been raised. He had from to time considered the question, and the conclusion he had arrived at was that in cases where the spans were not great, steel was not desirable. This was specially so if the girders were deep, and the sides of lattice or bar construction, because the sectional area of the parts, which were made of the same form whether in steel or iron, was so reduced that the girders became deficient in rigidity. In 1877 his firm designed a bridge nearly a mile long, which was erected over the River Nerbudda on the Bombay, Baroda and Central India Railway. The spans were 180 feet, and the depth of the girder about one-tenth the span. Wrought-iron was used, and very properly so, as at that time there was a greater difference in cost between steel and wrought-iron than at present. It was possible that if that bridge had to be constructed now, when the relative prices more nearly approximated, that steel might be adopted, but of this he was not sure without again studying the question with the particular end in view. It would depend in a great measure upon whether it would be more economical to do so. Another matter also had to be considered, and that was the question of oxidation. Assuming that the two materials were alike in this respect—and it was probable that there was not much difference—the smaller the parts, the greater relatively would be the mischief by deterioration from oxidation, and the shorter would be the life of the bridge. If the Chittravati girders of 140 feet span had been made of steel they would have cost more than if made of iron, and would not have had the same rigidity. The question was asked whether it would

bridge deeper, and to answer this he would briefly summarize the past history of wrought-iron girders. It was only about forty years since they were introduced, and before that time nothing but cast-iron girders were used. Engineers at the outset were guided by experimental investigations made by Mr. Fairbairn and others. The rule recommended and generally adopted, was to make the depth of wrought-iron girders one-fifteenth of the span. After a time, however, and when the subject became better known, they were gradually made deeper. From one-fifteenth of the span there was a successive but very cautious increase to one-tenth, a not uncommon limit at the present time, but he had made the Chittravati girders about one-eighth of the span. He thought this was a reasonable limit to adopt, but in his own practice he did not prescribe any invariable rule, for the exact ratio was within certain limits not a matter materially influencing efficiency or cost. He knew that some American engineers were in the habit of making girders very deep, even to the extent of one-fifth of the span, but he for one would not venture upon excessive depths. The parts became so much attenuated that, notwithstanding there was no greater strain anywhere than the conventional 5 tons per square inch on iron, or $6\frac{1}{2}$ tons per square inch on steel, the superstructure rattled and vibrated when trains passed over at speed. In this country girders having excessive depths had not been adopted, and would not, he believed, be regarded favourably by the Government inspecting officers, and in India there was, in the interests of the public, a like strict supervision. There was not so much saving in weight as some had supposed in adopting girders of great depth. Additional braces and ties were needed, and he had found besides that they were relatively at a disadvantage in the matter of wind-pressure, for which provision had to be made. These circumstances went towards neutralizing even the saving in weight that would otherwise result from deepening girders, and to this again must be added the greater mischief from oxidation by reason of the reduced size of the parts, as in the case of steel girders just referred to by him. It had been assumed, owing, he supposed, to the circumstance that the conical part of the cylinders was sunk almost or altogether into the bed of the river —the top of the cone being generally at about the level of the ground (Plate 7, Fig. 1)—that therefore there was necessarily a contraction from 12 feet to 9 feet in the working diameter during the sinking, which would add to the difficulty of the operation. But the cylinders of the larger diameter would be

a length of the same diameter could be added temporarily until the full depth was attained. The ground outside could then be sloped away as far as necessary, the temporary length withdrawn, and the conical piece with the upper portion of the smaller diameter could be permanently fixed. If this plan had not been followed, as he had supposed it would have been, it was evident that the cylinders need only be contracted when sinking the last few feet, which would not be a matter of much moment. At all events he should have been sorry not to have reduced the diameter of the upper portion. To have omitted to do so would have added to the cost of the work unnecessarily. Besides, if the larger diameter of 12 feet had been continued to the underside of the girders, which was at most only about 20 feet above the bed of the river, the piers would have been unsightly, as their size would have been out of all proportion to their visible height and to the span of the openings. Mr. Berkley had alluded to cast-iron cylinders cracking during sinking. Mr. Hayter had referred to such occurrences in his opening remarks, stating that he had provided against the contingency by making the bottom length of wrought-iron strong enough to take up any strain that might be superinduced during the process of sinking. In conclusion he would remark that the Chittravati bridge was one of the least costly of the kind ever erected under like conditions, and at the same time the official and other tests proved that it was a structure of proper rigidity. He would only add that he was sure Mr. Stoney would be well satisfied with the favourable reception accorded to his Paper.

Correspondence.

Mr. Bouscaren.

Mr. G. BOUSCAREN said that with regard to the cantilever span of the Sukkur bridge over the Indus, Mr. Robertson's Paper was specially interesting to American Engineers, as illustrating some points of difference between the methods of bridge-building in vogue in England and America. The first question which the designer of a bridge must answer before the general features and details of his plan could be determined was, "How was the structure to be erected?" In the case of an 820-foot cantilever span, as at Sukkur, this question would very probably have been answered in America "by building out with a traveller;" and one of the principal reasons for this was, that large structures were now

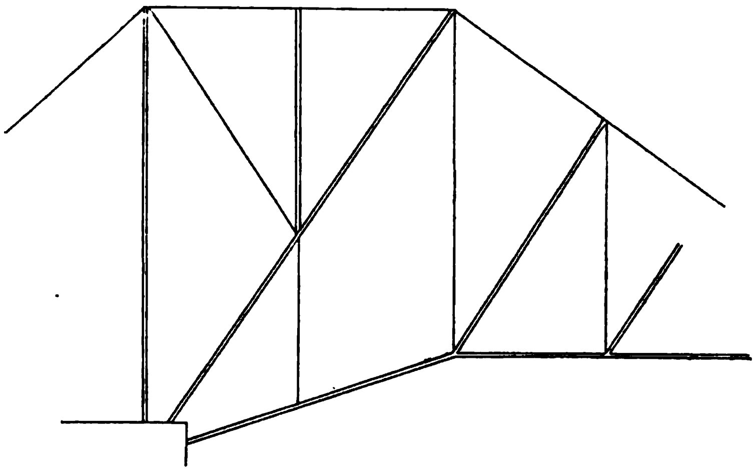
to confine themselves to the shop work, and sublet the erection to other parties who made a special business of that class of work, and were well equipped and trained to do it in that particular way. The result would probably have been a very different structure, especially as to details, from that designed by Sir A. M. Rendel. The commercial necessity of bending to the consideration of cheapness, arising from a keen competition, did not, perhaps, obtain in England to the same extent as in America, and left more latitude to the originality of the designer. The use of wire-rope carriers, although not a new feature in bridge erection, had been very ingeniously applied in this case, and seemed to have answered the purpose admirably, as no accident or mishap was recorded in Mr. Robertson's account of the work; but the time actually consumed in the erection of the span, from November 1887 to February 1889, seemed long, as compared with American practice, even after making all due allowance for the importance of the structure. Mention was made incidentally in Mr. Robertson's Paper of the large amount of drift carried by the river at certain seasons of the year, and this naturally called attention to the inclined booms at the abutment ends of the cantilevers, and the close proximity of the lower ends to the water suggested a liability to injury from drift, as well as danger to the crafts coming under the bridge at high water. It was a matter of regret to him that with all the valuable information given in Mr. Robertson's Paper, a little more had not been added with reference to the general specifications for the superstructure, as for instance, the live load designed to be carried by the bridge, the grade of steel used, and the limiting stresses per square inch allowed for the different members of the span. Such data would have been of great interest and value in comparing English and American practice at the present time.

The local conditions at the Chittravati bridge seemed to have been all that could be desired, and full advantage appeared to have been taken of them in the execution of the work. It was not clear, however, from Mr. Stoney's interesting account of the foundation work, why the inside curbing of masonry, which was found so useful in assisting by its weight in the sinking of the three cylinders under the north abutment, was not used as well for the cylinder-piers. The comparatively great cost of the pneumatic process as applied to some of the cylinder-piers for the removal of the large boulders appeared to have been due chiefly to the insufficiency of the plant; and with adequate machinery it seemed probable that time and expense could have

divers. In cylinder-foundations, where rock and boulders were liable to be encountered, he would give preference to wrought-iron over cast-iron for the cylinder-shells. With an inside curbing of masonry, no danger of deformation in the process of sinking from lack of rigidity need be apprehended, and the wrought-iron was better adapted to resist the air-pressure and the vibrations from the small blasts used in removing large boulders and levelling the bed-rock.

Mr. THEODORE COOPER remarked that the span of the Lansdowne bridge alone would make it a notable structure. The peculiar Mr. Cooper.

Fig. 3.



skeleton of its trusses, the extraordinary act of putting up each of its large cantilevers at the makers' yard before shipment, the difficulty of erecting the structure, and the statement of its cost, rendered it especially interesting to American bridge engineers. Facility and cost of erection did not seem to have received any consideration in the selection of the proportions of the skeleton. Without endorsing the general form of truss adopted for this bridge, he thought that a very slight change in the triangulation would have been a great improvement, especially when the erection was considered. Mr. Robertson's description of the steps necessary in order to connect together the first panel of the cantilever, emphasized very strongly the faulty division of the truss at this point. Had it been subdivided by a vertical line,

Mr. Cooper. making two panels of 61 feet 6 inches, and a diagonal tension-member extending from the top of the pillars to the centre of strut No. III, as in *Fig. 3*, it could all have been erected and made self-sustaining by means of a crane or derrick of only moderate reach. The reduction in weight by thus sub-dividing the present long members, and therefore lessening the bending strains, would have exceeded the additional material needed for the new members. Other modifications could have been made, having in view the same object. The absence in this design of features considered so essential for economy and facility of manufacture and erection by the American bridge-builder, rendered an examination of the statement of cost very instructive. The total weight of iron in the trusses was given as 3,316 tons, and the cost of the ironwork was Rs.17,01,000, or £120,487, taking the Author's rate for a rupee. The cost of the erection was Rs.5,61,223, or £39,753, omitting photographs and labour for painting. These figures made the cost of ironwork £36 6*s.* 8*d.* per ton; cost of erection £11 19*s.* 9*d.* per ton, giving a total for ironwork erected of £48 6*s.* 5*d.* In addition, it was difficult to exactly apportion the other items, such as charges for quarters, workshops, boats, plant, and contingencies, which would probably bring up the above amount to £50 per ton in the finished bridge. Presumably the cost of the ironwork alone, as above given, included that of the preliminary erection at the makers' works. Assuming that this, together with the taking down again, would amount to as much as the second erection, nearly half the money was expended in this way. As the cost of erecting such a bridge should not have exceeded £6 per ton, and as, according to the American practice, accuracy of length of the parts and correctness of fitting of the connections would have been attained without the preliminary erection, American bridge-builders would gladly have discounted the actual cost of the ironwork erected to the extent of £18 per ton at least.

Mr. Fidler. Mr. T. Claxton Fidler said the two bridges described in these Papers could hardly be compared. They presented a wide contrast in the lines of their design, and if possible a still wider one in the means adopted for their erection. At Chittravati the engineer boldly ventured down upon the bed of the stream, and making the best use of the dry season, succeeded in erecting his long line of girders by a method of the greatest simplicity, and at the lowest possible cost. But at Sukkur the erection of the cantilevers over the rapids in that confined gorge of the Indus presented difficulties of a very different order, which were surmounted by the employment of the

ingenious system of wire-rope transport described in Mr. Robertson's Paper. Of course the Sukkur bridge was not the first that had been erected by a method of overhead suspension; but in this example the appliances seemed to have been worked out, in all their details, with great ingenuity, and being admirably adapted for the difficulties of the situation, they appeared to have been employed with perfect success. In connection with this wire-rope rigging, there were one or two points on which some further information would perhaps be desirable. Whenever a member of the web-bracing was sent out for erection, it had to be suspended in a transversely battering direction, and the head of the piece was held in its true position by a rope or pair of ropes, hanging in the vertical plane of the top member; but to give it the requisite lateral spread at the foot the heel-rope must apparently have been worked from some sort of yard-arm, or spinnaker-boom, rigged out laterally from the gallows-frame. Something of this kind was incidentally referred to in the Paper, but the drawings did not show this spinnaker-boom, and it would be interesting to know its length, and how it was rigged and worked. It appeared also that, in a general way, the pieces were picked up from barges moored out in the river, but sometimes the barges could not be used, and on such occasions the Author did not explain by what course the pieces were taken out into position, and how they were steered up aloft so as to avoid fouling with the existing work. Another remarkable feature was the preliminary erection of the cantilevers on staging in the makers' yard. It would probably occur to most engineers that the construction of this great timber scaffold must have been attended with an expense which seemed disproportioned to the object in view, if that object was nothing more than to present the parts together so as to secure their accurate fitting; although the adjustment of such members, meeting at varying angles of transverse inclination, might very likely have been a complex matter. It was obvious, however, that such a proceeding would greatly facilitate the erection in mid-air by this wire-rope system of suspension; and perhaps the timber stage at Millwall, and the wire-rope rigging at Sukkur ought to be considered as complementary parts of the same scheme. It would be interesting to know how far they were so regarded by the engineers engaged in the work. Apart from the method of its erection, the Sukkur bridge presented some remarkable features in its design, which might be an interesting subject for discussion if the materials were at hand. But the Paper was concerned with the erection rather than with the

Mr. Fidler.

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At Niagara and at Brooklyn, Roebling appeared to confirm the idea that suspension-cables alone offered such a combination of lightness and tenacity as could be trusted for spans of such size; but a method of constructing rigid arched-ribs was making its way, in which wire cables or back-stays were used only as a temporary support for the permanent structure during the successive phases of its erection. In this way the cast-iron arch of 230 feet span, over El Cinca in Spain, was built in 1866 by Messrs. Schneider and Co. of Creusot without any scaffolding; and by the same means, in 1873, Eads erected the three great steel arches at St. Louis, which were again surpassed in width by the Garabit arch of 541 feet, and by the arches of Maria Pia and of Dom Luis at Oporto, which were executed by Messrs. Eiffel and Seyrig, and all of which were erected without any staging, by the aid of wire-rope stays. At St. Louis the temporary suspenders were accompanied by trestles of timber which abutted upon the piers, and flanked them on either side in the manner of cantilevers. But if the cantilevers were capable of sustaining the weight of the permanent bridge, why could they not take its place in sustaining the weight of the train? Such was the consideration which had guided Messrs. Fowler and Baker in spanning the Firth of Forth. Like the shooting stem of a plant, the cantilever sustained by its own strength the successive elements which it assimilated in its progressive growth; so that the temporary supports, instead of having to carry ultimately the whole weight of a semi-arch, had only to carry the fractional members of the structure, which themselves were gradually built out by the aid of movable platforms. From the day when this method of building not only chimney-shafts and light-house towers but also inclined members, was learnt, the art of erecting colossal structures made a new and rapid advance. The Rori girder was a modern witness of this fact, and it remained only to record in fitting language the consummate ability of the engineers, and the coolness and bravery of the workmen of all ranks who had co-operated in its erection. Some slight criticism might, however, be offered on æsthetic grounds. The Forth bridge had been objected to on account of its inelegant appearance, which was like that of a huge mass of scaffolding; although nothing could be more rational than its general outline, which recalled the figure of a diagram of bending moments in a continuous girder, with its parts grouped symmetrically about the supports. But it must be avowed that the appearance presented by the Sukkur bridge seemed far from being an artistic improvement. The logic of it, certainly, was conspicuous enough. Every stage Mr. Gaudard.

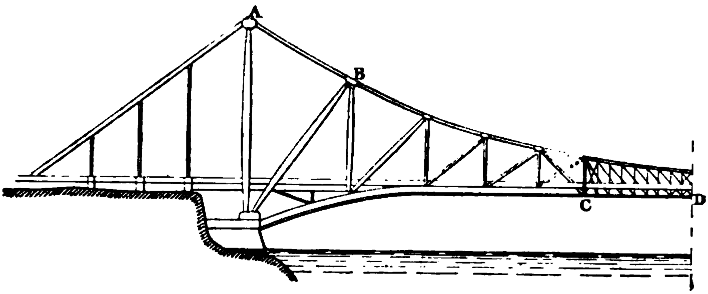
latter had been made use of to sustain the foot of the vertical member IV (Fig. 1, Plate 4), just as a pier would support it; hence this vertical might be treated as forming a counterpart to the pillar A, with which it was connected by the horizontal member AB; while from the summits A and B reached in each direction the back-stay or "guy," and the tie BE, sloping with symmetrical inclinations. But it was precisely this false symmetry about a wrong axis that had something hipped and limping about it. The jump or sudden change of height which occurred at the end of the central span, separating it from the pointed nose of the cantilever, expressed the articulation of the system; but the defect of level was not without an injurious effect upon the appearance. It was not clearly apparent why the struts of the web-bracing should change the direction of their inclination on each side of the vertical II; and moreover, the swelled form of the great struts was perhaps a little exaggerated. It would be interesting to discuss the comparative merits of this connecting-rod form, and of the tubular form adopted at the Forth bridge, which was more consolidated, well able to resist compressive stress, and lent itself easily to the progressive shifting of the movable platforms, but presented on the other hand the inconvenience of a complicated intersection at the joints of the framework. If, then, cantilever bridges aspired to better æsthetic conditions, it appeared that for them, beauty could hardly consist simply in "the splendour of truth;" but that, as architects confessed when they built false windows, art sometimes demanded a little dissimulation.

Mr. Gaudard then referred to a preliminary design prepared by Messrs. Bartissol and Seyrig for a bridge at Lisbon.[1] Proposing a system of cantilevers, the Authors disguised the break at the articulations under the elegant appearance of arches with a continuous elliptical curvature, sacrificing the logical form of the central girder, which was made to decrease in height towards the centre instead of giving it the rational bowstring form. In structures placed above the bridge-platform, it was at least possible, in default of the arch, to imitate the curvature of a suspension-bridge. The girder at Rori, for example, might be modified as in *Fig. 4*. Referring to the Chittravati bridge, Mr. Gaudard remarked that it was a very substantial work, the features of which

[1] Paris. imp. Barré, 1889.

had doubtless been dictated by local conditions connected with the transport of materials and the employment of native labour. The old bridge having been undermined, the constructors of the new one had desired, at any cost, to sink the foundations down to the solid rock. With the object of employing, as far as possible, an economical construction in concrete, they had recourse to cast-iron cylinders, which were mostly sunk with open tops to facilitate the dredging, although they had not neglected to avail themselves of subsidiary appliances, such as pulsometer pumps, diving operations, and the use of compressed air. But although piers founded upon the rock might well justify the adoption of continuous girders, they had employed independent girders throughout, and this form had probably been selected in consequence of the separate erection of each span upon the bed of the river. Subject to these considerations, Mr. Gaudard went on to indicate the points Mr. Gaudard.

Fig. 4.



in which this work seemed to differ from the prevailing tendencies of continental practice. Since the execution, in 1859, of the foundations of the bridge at Kehl, by Vuignier and Fleur-Saint-Denis, masonry piers in single blocks had generally been preferred to multiple columns with cast-iron casing—a preference which was even more strongly grounded in the case of a narrow single-line bridge. The pier could be kept plumb in the process of sinking with great certainty; and if any deviation took place, it was of less importance when the constructor was relieved of the necessity of fitting bracings, or connections between the columns; the progressive building of the masonry, *pari passu* with the sinking, dispensed with the employment of auxiliary loads—at least in the case of pneumatic sinking, which required only small shafts; and lastly, there was the endeavour to reduce the employment of metal in the piers, even though it might be attended with certain risks of settlement or cracking when the upper part of the

the old bridge rested in the sand, without reaching either the clay or the boulders; at the depth where the boulders were buried, they would seem to be safe from undermining, and to constitute a sort of coarse concrete nearly as good as that concrete by which they were replaced. If, when the cylinders had been sunk more than 50 feet below the river-bed, a material was met with that was difficult to excavate, the fact was an indication that the sinking might be stopped with perfect safety. Probably the screw-piles which had held good in the old work, had reached the point of refusal at the first large stones that were met with; and the conclusion that it would have sufficed to stop sinking on meeting the boulders, seemed to be again confirmed by the weight of rails employed to force the descent of the cylinders. For example, pier No. 11, when empty and undermined at the base, carried 444 tons of rails (222 on each cylinder), while the pier when completed and properly bedded, would only have to carry 160 tons of dead load, and 177 tons of test-load, or 337 tons altogether. The frictional resistance varied with the depth and with the lateral pressure exerted by the soil. If the soil was supposed to be without cohesion at all depths, so that the total pressure increased as the square of the height, the idea of a pressure per square foot, the variations of which were shown in Table II, might be replaced by an abstract number or a coefficient of friction, constant for any given material. As it was difficult to estimate correctly the pressure of earth, it had been proposed to take as a basis of comparison the simple pressure of water. Applying this idea to the friction of 2·13 cwts. per square foot, given in Table II, and referring to the depths, of which the mean was 41 feet, the following results were obtained:—Friction for this depth $= 2 \cdot 13 \times 41$; corresponding imaginary pressure of water $= 0 \cdot 2787 \times 41^2$; ratio $= 0 \cdot 19$. Table I, with a mean friction of 2·71 cwts. for a mean depth of 55 feet, gave a ratio of 0·18, agreeing very well. In the case of metallic caissons sunk in gravel or sand the value of this coefficient had been found to be from 0·4 to 0·6; but its value would be greatly influenced by the unknown degree of the cohesion of the soil in the deep beds. The ruptures occasioned by the explosion of dynamite might be referable to the want of space, for in the vast caissons at Brooklyn powder was employed without danger. However, cylinders of 8 feet 2 inches had been quoted at Palma del Rio on the Guadalquiver, where explosives were used to produce a kind of earthquake, with

a view of prompting the descent. The last observation he would make with reference to the Chittravati bridge was that with foundations which were at once sufficiently costly, and abundantly safe, European practice would certainly have increased the width of the spans and connected the girders. The bridge at Bordeaux had piers of the same calibre—that was to say, they consisted of double columns, 12 feet in diameter, but without tapering at the top—which carried girders of 254 feet span, and that with a double line of railway. The foundations had been carried down to the gravel (by compressed air) at a mean depth less than that at Chittravati, viz., 25 to 56 feet below the bed; while the total height of the columns was from 78 to 87 feet. It did not appear that the very convenient process of erection employed at Chittravati should constitute an imperative reason for abandoning the continuity of the girders. In an analogous case, Robert Stephenson united the tubular girders of the Britannia bridge over the piers, although their acquired deflection rendered the continuity imperfect. But now that the method of accurately calculating the deformations was known, the theoretical conditions admitted of being more perfectly realized. When a new girder in the series had been lifted into place, it was only necessary to give to its forward extremity a super-elevation, so as to make the rear extremity prolong tangentially the deflected line of the preceding girder; and then, when the riveting was done, the letting down of the forward extremity upon the bed-plate would procure for the preceding span the relief afforded by continuity in respect of the dead load. Mr. Gaudard.

Mr. THOMAS GILLOTT noticed with approval in the Chittravati bridge that the plates and angles in the boom-joints, where separated for shipment, were broken with splices, and not square across, as was often done. This involved more riveting on the site and greater risk of damage in transit, but made sounder work; and he asked the Author whether any injuries occurred during conveyance, such as would cause him to alter the breaks of the plates and angles, had such a design to be repeated. The number of rivets in each span requiring to be put in on the site (11,336) was equal to seventy-seven rivets per ton of work, which was somewhat high, seeing that the bridge had not a plated floor; and he would ask the Author what percentage of loose rivets put in by the native workmen had to be cut out on inspection. Some of the important ones connecting the cross-girder ends through one boom web, gusset, and vertical strut, appeared as though they would have to be knocked down single-handed (*i.e.*, by one man), and if the points were heated in a fire it would not be easy to Mr. Gillott.

Mr. Gillott. get the holes well filled under the rivet-heads. This led him to point out the advantage of the portable compressed-air riveters which he had recently adopted, and by which the greater part of the work could have been closed. A portable furnace with an air-blast would heat 200 or 250 ¾-inch or ⅞-inch rivets of average length per hour, with a consumption of about 1½ gallon of creasote oil, costing in this country *2d.* to *2½d.* per gallon; and as they were heated throughout their length, the holes were far better filled than when only the points were made hot, as was done when an ordinary fire was used. As an air-pressure of 45 lbs. per square inch would suffice for ⅞-inch iron rivets, there was no trouble with leaky joints, or burst hose-pipes, and the work of one of these machines was equal to that of three sets of hand-riveters. This was an important item in the erection of bridges, and he would direct attention to the advisability of the designs being prepared so that power-riveters could be used as much as possible.

Mr. Hogg. Mr. C. P. Hogg remarked that with reference to the information given by Mr. Stoney as to surface-friction in sinking the cylinders of the new Chittravati bridge, it might be observed that the friction per square foot of imbedded surface depended not only on the nature of the strata, but even to a greater extent on whether the cylinders were exactly vertical, for the greater the deviation from the vertical, the greater would be the friction per square foot. In the Alloa railway bridge across the Forth, erected in 1882–84, there was nearly 2,000 lineal feet of cylinder sinking. The cylinders were 5 feet, 6 feet, and in some piers 8 feet in diameter. During the progress of the works several good opportunities occurred for accurately observing the surface-friction, and the engineers, Messrs. Crouch and Hogg, MM. Inst. C.E., found it to vary from 2 cwts. to 5 cwts. per square foot, the higher rates being observed when the cylinder was out of the vertical, or on resuming work after the operations had been suspended for several weeks. One of the 8-foot cylinders was sunk 74 feet below the river-bed through the following strata:—

	Ft.	Ins.
Silt and sand	2	0
Muddy sand, clay, and stones	14	0
Sandy mud, and stones	14	0
Running sand, mud, and stones	17	0
Hard sand, stones, and clay	2	0
Blown sand	14	0
Clean sand	9	0
Hard gravel, sand, and clay	2	0
Total	74	0

At the finish, the surface-friction was 2·37 cwts. per square foot of imbedded surface. In the observations made at the Alloa bridge there was nothing to show that, under similar circumstances, the surface friction increased per square foot as the depth increased. This had been quite confirmed by observations made during the sinking of the caissons of the Dalmarnock bridge, just completed by Messrs. Crouch and Hogg across the Clyde at Glasgow. The caissons for the piers of Dalmarnock bridge were constructed of wrought-iron, and were sunk by the pneumatic process from 50 to 55 feet, through fine muddy clay and sandy mud. They were of an oblong form, with parallel sides and semi-circular ends, the dimensions at the cutting edge being, length 63 feet, and width 9 feet, and at 56 feet above the cutting edge, length 62 feet 3 inches, and width 8 feet 3 inches. On account of the large area of imbedded surface the observations were of considerable value. The results were given in the accompanying Table, and might be compared with those on p. 290 of vol. li. of the Minutes of Proceedings. The net sinking-weight in the Table was the weight of the caisson, concrete, air-locks, &c., minus the lifting force due to the air-pressure in the working chamber at the moment the caisson began to sink. The values of the surface-friction were probably somewhat high as the caissons were slightly twisted. Mr. Hogg.

TABLE OF SURFACE-FRICTION AS DEDUCED FROM OBSERVATIONS MADE DURING THE SINKING OF THE CAISSONS OF DALMARNOCK BRIDGE, GLASGOW, BY THE PNEUMATIC PROCESS.

Caisson.	Depth of the Cutting-Edge below the River-Bed.		Area of the Imbedded Surface of Caisson.	Net Sinking-Weight = Weight of the Caisson, Concrete, &c., minus the Lifting Force due to Air-Pressure.	Surface-Friction per Square Foot of the Imbedded Surface of the Caisson.
	Feet.	Ins.	Square Feet.	Cwts.	Cwts.
No. 1	38	9	5,251	18,974	3·61
	46	6	6,301	24,674	3·92
	49	5	6,684	25,754	3·85
	53	5	7,211	25,754	3·57
No. 2	47	1	6,380	22,594	3·54
	53	0	7,155	24,640	3·44
	54	1	7,301	24,640	3·37

Mr. Robertson, on the Lansdowne bridge, being confined to a description of the mode of erection, with but general reference to the design, must necessarily narrow the range of discussion within limits which were scarcely adequate to the importance of the subject. The problem was to construct a bridge across a clear opening of 790 feet, without the use of temporary supports from the river-bed; and as a matter of course, with due regard to the cardinal principle that the best engineering was that which most fully answered its purpose at the least cost. The cantilever type of superstructure was doubtless selected by reason of the fear that the false works required to sustain a simple girder during erection would be carried away by drift. At this distance, and without sufficient knowledge of the river in question, it was impossible to say whether a different design would not have been advisable. If there were any periods of quiet water on the Indus, and if such a period (which need not exceed eight weeks) could have been relied upon at any given season of the year, it was safe to say that a plain truss of 800 feet span, between the centres of the end supports, could have been substituted for the present design at a greatly reduced cost. Assuming, however, that the cantilever type was the most available, it was not probable that the particular arrangement adopted at Sukkur would be repeated, from motives of economy, at least. Referring to the table of weights it would be seen that after deducting roadway and rails, the structure weighed 3,220 tons, distributed as follows: from anchor to centre of pillar, 420 tons, each side; from centre of pillar to centre girder, 1,062 tons, each side; centre girder, 256 tons. From this it appeared that the weight per lineal foot of the several divisions was as follows:—

$$\text{Anchor arms, } \frac{420 \text{ tons}}{247 \cdot 77 \text{ feet}}, \ 1 \cdot 7 \text{ ton, or } 3{,}808 \text{ lbs.}$$

$$\text{Cantilever arms, } \frac{1{,}062 \text{ tons}}{310 \text{ feet}}, \ 3 \cdot 42 \text{ tons, or } 7{,}660 \text{ lbs.}$$

$$\text{Centre girder, } \frac{256 \text{ tons}}{200 \text{ feet}}, \ 1 \cdot 28 \text{ ton, or } 2{,}867 \text{ lbs.}$$

The disparity between these figures indicated an unscientific division of lengths, as between the central span and the cantilever arms. An increase of the length of the centre span would undoubtedly result in a decrease of the total weight of the bridge. The most striking feature, to an American engineer, in this table

of weights, was the excess of material required over what would be considered the best practice in the United States. It was quite within bounds to assert that a saving of at least 30 per cent. might have been made by a re-arrangement of the general proportions and modification of details so as to permit of economical erection; and this, without in the least impairing the strength or durability of the structure. It was to be regretted that the cost of the Sukkur Channel was allowed to appear in this connection, as the tendency was to confuse the statement of cost of the Rori Channel, which was the only one calling for special remark. The item marked ironwork for the Rori Channel was put down at Rs.17,01,000, which, converted into pounds sterling per ton (assuming the value of the rupee to be 1*s*. 5*d*., and the weight 3,316 tons) became £36 6*s*. 8*d*. Probably a considerable part of this cost was to be accounted for in the expense of assembling "the entire steel-work upon a timber scaffold in the makers' yard before shipment," as reported by the Author. A bridge which was properly designed, and faithfully inspected during its manufacture at the shops, was certain to come together on the ground; and there could be no excuse for compelling the purchaser to pay the extra expense of shop erection, unless it was to shift the responsibility of accuracy from the shoulders of the engineer to those of the manufacturer. Hundreds of thousands of tons of bridge-work were erected in America every year; and, if a single span had been assembled at the shops during the past decade, it had been the exception to a universal rule. The methods pursued in erection appeared to have been judicious and economical, considering the difficulties inherent in the design. The cantilever presented most favourable conditions for the men in the field, when the details were so arranged as to permit of movable derricks. In this case, if the original design had involved a permanent tie from the top of the pillar to the middle of strut III, with a suspender from this intersection to the floor, and a strut upwards to the horizontal tie, a great saving in weight and in cost of erection would have ensued. The erection appeared to have cost £12 3*s*. 6*d*. per ton, irrespective of some small items of general expense. This was equivalent to 2·63 cents per pound, American money; and was about double what similar work was done for in that country. It was scarcely reasonable, however, to criticize the cost of work when men were subjected to a normal temperature of 100 degrees, with a maximum of 180 degrees in the sun. The wonder was that so much was accomplished, under such unfavourable conditions. Mr. Macdonald.

Mr. Macdonald. The delays occasioned by the removal of boulders from many of the cylinders would seem to indicate that the pneumatic method of sinking might have been used to advantage in the Chittravati bridge. It was a matter of surprise to note the high cost of what little was done by this process as compared with dredging and diving. In America, in all western rivers where the bottom was liable to scour, it was the custom to sink masonry piers by compressed-air, the caisson containing the air-chamber being constructed of timber. By this method it was comparatively an easy matter to remove obstructions, and when the element of time was considered the total cost of the work was greatly reduced. In the case of the Indian rivers, where masonry was not required to resist ice, it was a good practice to build cylinder piers; but it would be quite possible to connect the cylinders in pairs by an air-chamber at the bottom, supplying the weight for sinking by piling loose stone upon the space between them, and if necessary carrying up a concrete lining inside. By this method the boulders which caused so much delay in piers Nos. 10 to 14, could have been taken up through the air-locks at moderate cost, and nearly all the expense attending the loading and unloading of the cylinders would have been saved. The superstructure of the Chittravati bridge was said to be of the Murphy-Whipple type. This was rather a strained application of the term. Messrs. Murphy and Whipple were pioneers in developing a system of bridge construction specially adapted to rapid and economic erection, in which the principal members were connected by pins, and the only field-rivets required were of secondary importance. A truss, such as either of these gentlemen would have designed for similar spans to those at Chittravati, could have been coupled up and made self-sustaining in a few hours, and the completion in every detail assured within three days. In the bridge described in this Paper there were no less than eleven thousand three hundred and thirty-six rivets to be driven in each span before it was ready to be lifted into place; and this fact should make an engineer hesitate before selecting a type of construction which involved so many chances of imperfect work in the field, to say nothing of the increased risk of loss from flood, owing to the prolonged exposure upon the supports; or of the extra cost of doing work by native labour which might have been done to better advantage at the shops. The amount of metal put into bridge trusses in India, judging by the examples described in recent professional papers, could not be accounted for upon any rules of economic proportion with which American engineers

were familiar. The train-load could not be heavier than that in use in the United States, and the factor of safety was substantially the same. Why, then, should a span of 140 feet over all weigh 146 tons 12 cwt. in India, while a span of the same length, strength, and durability, weighed but 80 tons in America? It would be of interest to know whether the equation of cost between the piers and superstructure was such as to give minimum results for the completed structure. The total cost was given as £101,428, which seemed excessive for the length of the bridge involved; but in the absence of detailed statements, it was impossible to determine where the excess, if any, arose. Mr. Macdonald.

Mr. T. SEYRIG said, that in the erection of the Sukkur bridge, it became necessary to employ successively several different methods of work. This appeared to go a long way towards deciding whether the original design of the structure was entirely adequate. It was at once elaborate and complicated. The apparent simplicity of the general lines seemed in a large measure to have lost its advantages in the complication of the details. It had also led to the result that in the erection very heavy parts had to be handled. Except in special cases, it could not be advantageous to lift pieces weighing as much as 14 tons, and this would most probably have been avoided if the work on the spot had been more considered while designing. Bearing in mind the questions of ease and safety, and more especially economy of erection, the best practice would limit the weight of parts to be lifted to 2 or 3 tons, and this was particularly the case when rope tackle had to take the place of staging. As it was, the erection of a single span had necessitated not only some important wood staging, and a complete set of rope tackle, but also a temporary iron staging for the central span. The result told upon the total cost, which amounted, including special plant, to about Rs.811,000, or £57,450 for 3,316 tons. Making allowance for all special circumstances, distance, &c., £17 6*s.* per ton was certainly a very heavy price when compared with what had been realized elsewhere, owing to better provision in design. Mr. Seyrig.

The difficulties encountered (and so frankly stated by the Author of the Paper on the Chittravati bridge) during the sinking of the cylinders, were typical of such undertakings, and they seemed to raise once more the question whether it was really best to sink cylinder-foundations by dredging. It was true that in soft ground and at moderate depths it could be easily and safely managed; but the slightest accident would sometimes upset all provisions, often more than doubling both time and cost. In the Chittravati

old, and the cylinders often cracked through previous blasting operations. Under such circumstances, it was impossible to consider the work done, and its cost (443 rupees per lineal foot), as at all representative of what it should have been if the greater part of the sinking operations had been done pneumatically. The mean cost of sinking, deducting the portions done by hand-labour, was 42 rupees, or £2 19*s*. 8*d*. This price could certainly have been considerably lowered if pneumatic appliances had been used throughout, and it was moreover certain that the possibility of examining the ground during the process of cleaning the bearing surface, and of laying and ramming the concrete when the excavation was completed, were advantages which increased the value of the whole work to such an extent that Continental engineers now almost universally avoided any method which did not insure the examination of the foundation ground *in sitû*, and at the same time prevent the inconvenience and danger of depositing concrete under water.

Mr. Wilson. Mr. JOSEPH M. WILSON remarked that the two bridges under discussion presented widely different conditions in reference to design and facilities for erection. While the total length of the Chittravati bridge was considerable, the spans were comparatively short, and allowed the adoption of an economical type of superstructure, which called for no special comment, except that in noticing the American form of outline with its familiar name of "Murphy-Whipple," he could not but observe the absence of pin connections, which to an American mind would have considerably facilitated the erection. The engineer was to be commended, however, for the skill with which he had availed himself of the natural advantages of the location, in constructing the sub-structure as well as the superstructure, and for having successfully completed the work in what Mr. Wilson believed to be a very short time as compared with Indian work generally. It was well known that the development of pin-connected trusses of this type, having vertical compression and inclined tension web-members, had reached high perfection in the United States. The uncertainty of the strain, however, in the inclined web-members towards the centre of the span, where ties and counters occurred in the same panels, together with other considerations, had led some engineers, himself among the number, to favour the adoption of triangular trusses, where certain web-members were exposed to alternating stresses of tension and compression, according to the position

Mr. Wilson.

of the moving load. He had had considerable experience in the inspection of bridges in service, and had never observed any wearing action in the pins of structures of the "Murphy-Whipple" type, even after years of use, and in cases where the pins and links were not designed according to the most modern ideas in reference to areas of bearing surfaces, bending moments, &c. His attention had been called, however, to the case of a bridge of his own design on the triangular system, where an action was noticed on the pin which had never been observed before. It was a small structure in which the effect of the variable live-load was severe as compared with the dead-load. After it had been in service for about five years a change in the alignment of the road necessitated the removal of this bridge to another location. In taking it down it was discovered that the pins had been worn into grooves at the bearings of the links, in some places as much as one-eighth of an inch in depth, these grooves being almost as clearly defined as if cut by a tool. The pins and links had been well proportioned for bearing surface, and it was evident that the result had been due to the turning of the pins in place. It was thought that the action of the alternating stresses in the links, first a push and then a pull, caused this rotary motion, and that if the pins had been secured from turning the difficulty would not have occurred. Where the stresses in each member of the truss were always of one kind in the same member as in the "Murphy-Whipple" type, giving a constant bearing on the pin, there did not appear to be this tendency to revolve.

He observed that the Sukkur bridge, in common with other cantilevers, presented an obvious mode of procedure in the erection, but the large sizes and weights of the members to be handled required careful treatment, and the work seemed to have been well carried out. As there were evident delays in the receipt of material from England, no criticism could be made on the time taken for the erection.

Mr. Hayter.

Mr. Harrison Hayter, Vice-President, would, in the absence of Mr. Stoney, reply to the correspondence in so far as it related to the Chittravati bridge, and had not been noticed in his previous remarks. Much of the correspondence was from America, and it was useful to know the views of American engineers on English practice. In reply to Mr. Bouscaren, he assumed that Mr. Stoney had not used an inside curbing of masonry to assist in sinking the cylinders of the piers because he would not desire to contract the working space, and also, probably,

were flanges, ribs, and bolts; this objection would not hold in the case of concrete which was used for the filling inside the cylinders, and which no doubt also would cost much less than masonry. As regarded the adoption of the pneumatic process for sinking cylinders, he had used it extensively, but he was opposed to it if it could be done without, especially if the cylinders were in deep water. Men working under air-pressure did so at a disadvantage both as regards progress and bodily discomfort, and often at the sacrifice of health. He did not believe that the cost would in any way have been lessened, as Mr. Seyrig also seemed to think, if the pneumatic process had been adopted throughout, and he considered Mr. Stoney had done well in limiting its use. Mr. Hayter had used elsewhere cylinders entirely of wrought-iron up to the conical length, but they added to the cost and were not so readily put together as cast-iron cylinders made in segments bolted to one another. All that was necessary was to make the bottom length of wrought-iron as he had done in the Chittravati bridge, and if this were made strong enough to take the strain, there was little fear, under ordinary conditions, of the cast-iron cylinders cracking during the process of sinking. Mr. Jules Gaudard was right in the supposition that Mr. Hayter had designed the bridge with independent girders throughout, instead of continuous girders, in order to facilitate erection. Continuous girders could not have been so readily dealt with, and would have involved more riveting, and of a more difficult character. Continuity also added to the complication where the sides of the girders were composed of struts and ties and not of solid platework, and there were more parts not duplicated. He did not believe that any saving in cost would be effected by connecting the girders together over two or more spans in a case like the Chittravati bridge. He preferred two cylinders instead of one for the piers. A better base to the piers was thereby secured, and the surface-friction was reduced to a minimum in sinking. In designing bridges for India, and in like places where the climate was hot, and where the locality of the structures was at a distance from manufacturing centres, the greater the facilities that could be afforded to the engineers who erected the work, the more probable it was that success would be ensured and expense saved. He was not aware that any injury had resulted during transit by the plates and angle-irons where they were separated for shipment being broken with splices and not square across. He had followed both

plans, but he found that if the ends were well protected with temporary timbers they reached their destination uninjured, and sounder work (as Mr. Gillott remarked) was the result when the girder was erected. He believed that there was no more likelihood that there would be loose rivets with native riveters than there would be if Englishmen were employed. There was no reason, however, why machine-riveting, either actuated by steam, water or air, should not be introduced in India as well as in America or England. He agreed with Mr. Hogg that the surface-friction encountered in sinking cylinders depended not only upon the nature of the strata penetrated, but also upon the cylinder being kept vertical, and the table Mr. Hogg had sent was instructive. Compared with that given by Mr. Stoney it appeared that the surface resistance was much less in the case of the Chittravati bridge than in that of the Dalmarnock bridge, owing no doubt to the different conditions. Mr. Macdonald, from his connection with America, was probably unaware of the very proper restrictions imposed upon engineers with regard to iron bridges in England and India. The Chittravati bridge was designed with the authorized factors of safety, and with a limited allowance for deterioration, which was desirable now that iron bridges were being continually renewed or strengthened owing to oxidation and decay. He would not, as he had already said, sacrifice efficiency by making girders of the excessive depths sometimes introduced in America, but which would not be tolerated in England or India, and he considered that no material saving in weight would result if the deep girders were so braced and tied as to be as efficient as they could be made. The equation between the cost of the piers and superstructure was such, he believed, as to give the best results for the completed structure. Although the length of the spans was the result of a suggestion from India, they quite met his approval as being the most economical to adopt considering the conditions; and that the design of the Chittravati bridge was as suitable as could be devised seemed to be evident from the fact that whilst it was a rigid structure the cost was very low compared with that of other bridges across rivers of a like kind. Mr. Wilson seemed to prefer pin-connections, which Mr. Hayter had largely used, and which Mr. Wilson said would to an American mind have facilitated erection. The practice, however, in England differed from the American in this respect. The use of pin-connections was now rather the exception here than the rule, and the reasons for this preference should apply with greater force to iron structures which had to be transported

Mr. Hayter.

liability to alteration of shape by transport and climatic changes were unfavourable to the adoption of pin-connections on a large scale in such places as India.

16 December, 1890.

Sir JOHN COODE, K.C.M.G., President,
in the Chair.

The discussion upon the Papers by Mr. Robertson and Mr. Edward Stoney, descriptive of the Sukkur and of the Chittravati Bridges respectively, occupied the evening.

Sect. II.—OTHER SELECTED PAPERS.

(*Paper No. 2284.*)

"Tramway Permanent Way."

By James More, Jun., Assoc. M. Inst. C.E.

The utility of tramways, as a means of reducing the tractive resistance in moving a loaded vehicle, has been recognized since the seventeenth century, when rails of oak were employed. This primitive track has progressively developed into the substantial structure of to-day.

First, to lessen the wear, wrought-iron bars were spiked to the upper surface of the timbers, then cast-iron plates were used in the same manner, and latterly wrought-iron rails, rolled in different sections, were fixed in a variety of ways to the top of the oak beam, or, as it is now called, the longitudinal sleeper. This last system, with longitudinal timbers and rolled-iron or steel flat or box-rails, was almost invariably adopted till about the year 1870. By that time a great variety of systems had been introduced, having a substructure of cast-iron or a combination of cast- and wrought-iron, in the forms of sleepers and chairs, the rails used being of rolled steel of different sections, but generally of the box or web pattern. Then followed the rolled-steel flange rail similar to a railway flat-bottomed rail, but with a groove in the head like other tramway sections. The usual weight was from 40 lbs. to 60 lbs. per lineal yard, and for a foundation, some were bolted to plates 12 inches broad, some to longitudinal, and others to cross trough-sleepers of rolled iron or steel. Occasionally this rail was also used with ordinary timber cross-sleepers. Last came the girder-rail, and this is the rail most largely used at the present time. It is a flat-bottomed rail with deep web rolled to sections of from 60 lbs. to 100 lbs. per yard, having a flange from 6 inches to 7½ inches broad to take the place of the longitudinal wooden sleeper before referred to.

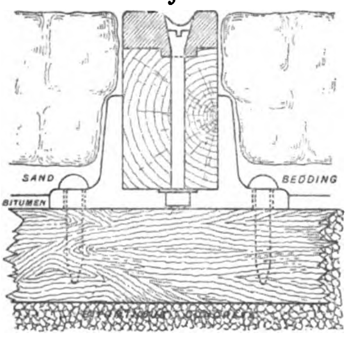
Having thus roughly traced the development of tramway permanent way, the Author will now discuss the merits and demerits of a few of the principal systems at present in use. Most of the defects to be noted have been proved by the Author experimentally. Of some of the more complicated systems he has no acquaintance;

in such cases he will only refer to such obvious objections as present themselves to his judgment. With the exception of the timber longitudinal-sleeper and box-rail systems, which were never satisfactory even with horse-traction, he has judged all the later systems by the standard of their suitability for steam-traction. A great many of the cast-iron chair and sleeper systems have been tolerably successful with horses, but have failed when a locomotive was run over them. Nearly all new companies now apply to Parliament for powers to use steam, and the Author thinks this standard of stability is not unreasonable, especially as a line may now be laid with girder-rails, which will carry a locomotive fairly well at as little, or less, cost as that of the built-up systems.

Longitudinal-Timber Systems.

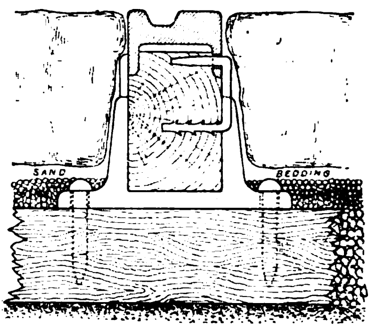
In the earlier lines laid upon longitudinal-sleepers, the rail was merely a flat bar, not intended to have any material vertical stability; but, relying for this on the sleeper, it was simply

Fig. 1.



Glasgow. First Contract.

Fig. 2.



Glasgow. Second Contract.

intended to supply a durable wearing-surface (*Fig. 1*). Here the mode of fastening by vertical holding-down bolts was the main deficiency; the rail, being so weak, deflected under the load. In front and behind the points of contact there was a corresponding rise or lifting of the rail from the sleeper. This, with a rolling load, of course gave rise to a series of concussions between the rail and sleeper, which in a short time loosened the fastenings, and wore the top of the sleeper to such an extent that ultimately the rail lay loose, and only bore on the sleeper while a load was passing over it. Hence resulted a vertical and lateral rocking motion, during the passage of any vehicle, which

soon caused the destruction of the bearing-surface of the sleeper, distortion of the rail, and loosening and crushing of the grouting at the sides. In wet weather the surface water found its way down the joint between the setts and the rail, and so under the sleeper and paving, carrying away with it the pulverized particles and bedding of the paving. The vertical weakness of this rail also caused great tractive resistance to a moving car, through deflection as the wheels passed over it; and, indeed, in this respect, some of the old lines laid on this system are little, if at all, better than a good macadamized road.

To obviate the vertical deflection, by stiffening the rails to some extent, they were afterwards rolled with vertical flanges at both edges in the form of a channel-bar. This form of rail is now called a box-rail (*Fig. 2*). The holding-down bolts having been found useless, to prevent the lateral rocking-motion, another variety of fastening, in the form of dogs or staples, was tried; with some success, but not sufficient to save the system from failure. The rail was not yet stiff enough, and still admitted of too much deflection during the passage of heavy traffic, and the vertical concussion soon loosened all the "dogs." The loosening process set up was similar to that employed by carpenters and scaffolders for releasing "dogs," where the blows applied to the outside of the dog effected the same purpose as the vibratory action and shocks caused by the traffic on the rail.

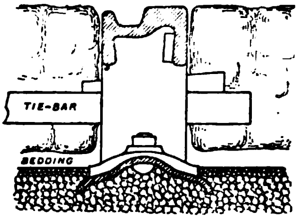
In the box-rail system it was usual to have a liner, or joint-plate, 8 inches to 12 inches long, and about $\frac{3}{8}$-inch thick, under the joints of the rails; but the Author thinks its failure might have been easily foreseen. It was merely a loose plate, subject to movement under a load, thereby greatly increasing the vibration at the joint, and the probability of water finding its way about the substructure. This box-rail has not been a success for horse-tramways, and when a locomotive has been put on it, the results in several cases have been disastrous. On the lines referred to, it is common enough to see the ends of the rails rise about an inch, before and after the engine has passed over the joint. This system, however, is obsolete, and forms merely a stage in the history of tramway development.

Cast-Iron Chair Systems.

These systems were designed presumably to overcome the unfortunate results of the wear on the top of timber sleepers, and the consequent loosening of the rails; and at the same time to form a more durable connection between the rails and the substructure.

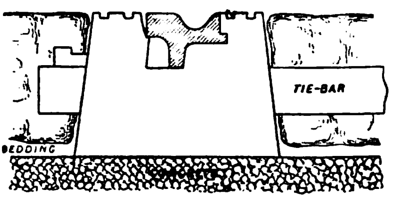
practical success, not fulfilling the necessary conditions of rigidity of rolling-surface, and durability of connection between the rail and the substructure, owing to the absence of means of periodically tightening the fastenings of the great number of separate parts. In the Author's opinion, other things being equal, the system with the fewest parts per yard is generally preferable to others. Close attention to the fastenings of a tramway is out of the question, as the paving would have to be lifted at every bolt or cotter, which, in the systems under consideration, would mean almost every yard. In fact, this kind of maintenance on a tramway is never anticipated, and seldom attempted, except when the paving needs repair. In a permanent way, while, to have a great number of bolts is bad, to have cotters is worse so far as

Fig. 3.



Livesey's.

Fig. 4.



Cockburn Muir's.

loosening is concerned, though cotters seem to be more popular. In some of these systems provision is made for tightening-up, by using vertical holding-down bolts, with slotted heads countersunk in the groove of the rail; but with this head it is impossible to get the bolt screwed up to any useful degree of tightness, owing to the feebleness of the hold on the head.

The Author will now briefly describe a few of the more generally used systems with cast-iron chairs.

Livesey System, Fig. 3.—This was largely used until recently in Buenos Ayres. The rail, which is a good specimen of the "Box" pattern, is fixed to the chair by a steel or wrought-iron key or cotter, driven between the chair seat and the inside of the webs. The chairs are bolted to a wrought-iron trough-shaped base-plate, and are tied by wrought-iron tie-bars fixed with a cotter.

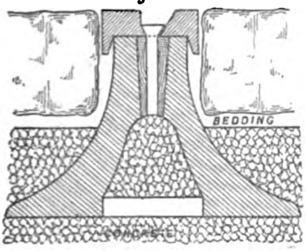
Cockburn-Muir System, Fig. 4.—In this system there is a heavy anvil-like chair, bedded on concrete, carrying a light T-shaped rail, which is fixed to it by a cast-iron dove-tail key under the

tread. A wrought-iron bar fixed with a cotter ties the chairs together.

Kincaid's Systems, Figs. 5, 6 and 7.—These three systems are similar in so far that the chairs are all of pyramidal form of extra depth, and anchored or imbedded in a concrete foundation, dispensing with the use of tie-bars. The rails differ in each type, and of course also their fastening to the chairs.

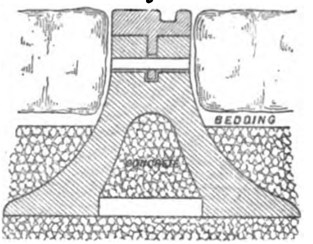
These types have done good service in several towns in this country.

Fig. 5.



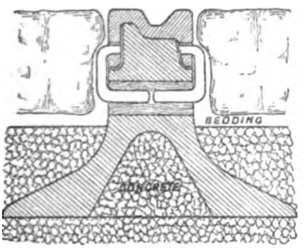
KINCAID'S.

Fig. 6.



KINCAID'S.

Fig. 7.



KINCAID'S.

Fig. 8.

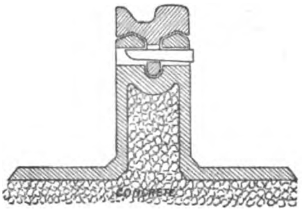
VIGNOLES'.

Vignoles' System, Fig. 8.—This has been in use in North Staffordshire under locomotives for many years, and differs in a marked degree from most other chair-systems.

The rail is of a good section, of tee-shape, 5 inches deep. It is hung on a single shoulder of the chair, which shoulder is on the outside of the rail-web, and on the inside there is a fish-plate of peculiar form. The fish-plate, web of rail and chair are bolted firmly together, and the chairs are spiked to cross-timber sleepers, which are imbedded in concrete.

Barker's System, Fig. 9.—It perhaps is hardly correct to class this with cast-iron chair systems. The so-called chairs are about 3 feet long with only ½ inch of space between their ends, and, as the rail has a bearing or bed on them to the full extent of their length (and so is practically continuous), they are more correctly termed "cast-iron longitudinal sleepers."

Fig. 9.



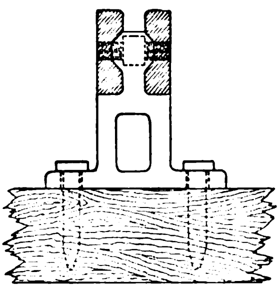
BARKER'S.

The system has been used to a considerable extent in important towns in this country.

The rail is tee-shaped and is fixed on the sleepers by a cotter passing through the sleeper or chair and the web of rail. The sleeper or chair is of good section as to rail-bed, and it has flanges 12 inches broad, affording a large bearing on the concrete foundations. Tie-bars are not generally used unless the line is to be laid without paving.

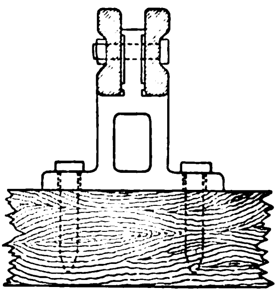
Beloe's Systems, Figs. 10 and 11.—Here a double rail is provided on each side of the track similar to the check rail on a railway curve, from which it differs in so far that the car-wheels having

Fig. 10.



BELOE'S.

Fig. 11.



BELOE'S.

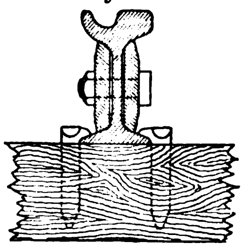
a central flange with a tread on both sides bearing on both rails, the space between the two rails acts as a groove.

As will be seen, *Figs. 10* and *11* are similar except in the mode of fixing the rails to the chairs. These chairs are spiked to cross-timber sleepers, which are imbedded in concrete as usual. It has been used, the Author understands, in several towns in this country.

Cross-sleeper Systems.

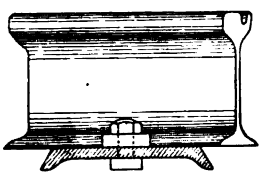
Contemporaneous with the last-mentioned types were the cross-sleeper systems, of timber and steel, where an ordinary flat-bottomed rail was rolled with a planed groove in the head, and otherwise like an ordinary railway rail. The head of the rail was first rolled in the solid, and the groove planed out, which was an expensive operation, and prevented the rail being a commercial success till a means of rolling the groove was found. The advent of this rail, as applied to tramways, marked an important era. It was first rolled in sections of from 40 lbs. to 60 lbs. per yard, and was laid on sleepers like a railway, but without chairs, and was merely fastened to the sleepers with dog-spikes (*Fig. 12*). The rails were joined by fish-plates and bolts in the usual manner. This track is easily laid, and, with macadam inside and outside of the rails, makes an excellent permanent way, using, say, a 60-lb. rail; and even with paving, where pitch grouting is used and the traffic is light, it stands very well. The rails in many car-depots are so laid. But the spikes are liable in course of time to draw slightly under traffic, and consequently the rail to rock laterally. To overcome this tendency it is now customary to use steel cross-sleepers, with a riveted and bolted clip to fix the rail to the sleeper, the riveted clip being on the outside of the rail. If the sleepers are properly packed up with concrete,

Fig. 12.



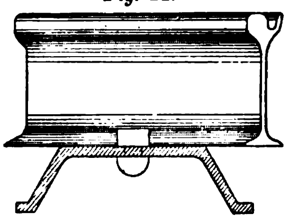
Cross-timber.

Fig. 13.



Steel Cross-sleeper.

Fig. 14.



Steel Cross-sleeper.

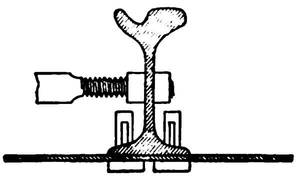
or, better still, beaten down on it till they are entirely bedded, this makes an excellent line. In the Author's opinion it is the best system for a foreign line where economy in construction is the first consideration. There are two sections of steel sleepers in use (*Figs. 13* and *14*), of which the former represents the one used in

the Alford and Sutton line in Lincolnshire, and in the Barbadoes line. Of the two the Author prefers the latter, as being stiffer, and having a much better bearing on the concrete, although not so easily packed with concrete. When the Author has had occasion to use those sleepers, he has beaten them well down on plastic concrete till they took a complete bearing. This is superior to packing.

Longitudinal Steel-sleeper Systems.

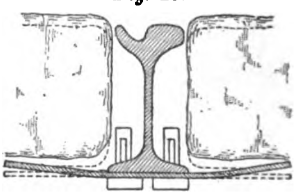
The Winby-Levick System, Fig. 15, is a further development of the flat-bottomed rail system, in combination with a steel or wrought-iron longitudinal sleeper, or base-plate. The rail weighs about 60 lbs. per yard, has an ordinary fish-joint, and a longitudinal base-plate or sleeper 12 inches broad by $\frac{3}{8}$ inch thick (*Fig. 15*). The rail is secured to this plate by cotter-bolts, and the whole is laid on a bed of concrete. The principal fault is the want of transverse stiffness in the base-plate, which sinks in the centre

Fig. 15.



Winby-Levick.

Fig. 16.



Winby-Levick.

where the rail bears (*Fig. 16*), thus raising the edges when a load passes over, and loosening the setts adjoining the rails.

John Kerr's System, Figs. 17 and 18.—The rail is about $5\frac{1}{2}$ inches deep, and weighs about 60 lbs. per yard where paving is to be used; but, where there is no paving, a section of less depth and of about 40 lbs. per yard can be substituted. This rail is fastened to longitudinal trough-sleepers of wrought-iron or steel. Two different kinds of fastenings are employed. The first is similar to that on the Winby-Levick system, namely, cotter-bolts, and the second is a pair of clips, one riveted on the outside, and one bolted on the inside of the rail. The rails are joined by fish-plates, and the rail and sleeper break joint to the extent of 3 feet 6 inches. The fastenings are 3 feet 6 inches apart, the cotter-bolts being on alternate sides of the rail. The Author prefers the clips, as the

holes for the cotter-bolts weaken the flange of the rail, and render it liable to break under the crow-bar or when bending is required. Also the clips admit of more play, and allow the rail to be bent to easy curves without affecting the sleeper. With these rails the Author has found it possible to get a versed sine of 2 inches in a 24-foot length, without bending the sleeper. When the curves are smaller, the sleeper may be curved by making several cross-cuts with cold sates, on the convex side of the curve, from the rail-flange to the edge of the sleeper. The smaller the radius the greater the number of cuts required, and a versed sine of 8 inches in a 24-foot rail may thus be obtained, which is about equivalent to a curve of 110 feet radius. For curves smaller than this the sleepers are supplied in lengths of about 3 feet 4 inches.

Fig. 17.

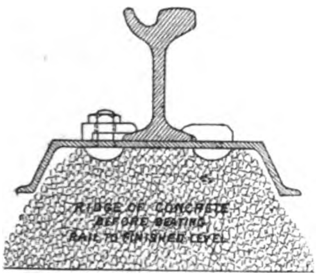
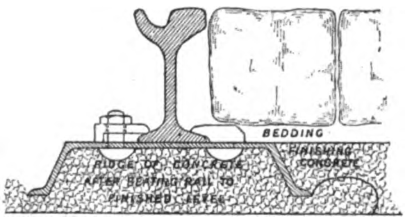


Fig. 18.



KERR.

In laying this system, after the ground has been excavated to the required depth, two ridges of fine concrete (the stone or macadam to pass through a 1-inch ring) are placed in the track of the rails. The rails, fixed to the sleepers, are put on the top of these ridges, and should then be about 6 inches above their finished level (*Fig. 17*). The sleepers and rails are now beaten down to their proper level, and the surplus concrete escapes under the sleepers (*Fig. 18*). During the beating the rails are held to gauge by temporary tie-rods dropped over their heads. The spaces between the metals and in the margins are now filled in, and floated to the level of the top of the sleepers with concrete, which, being allowed to set, the line is ready for paving. This system has been laid without tie-bars, which are unnecessary after the concrete is thoroughly set; but it has been found difficult to beat or ram the paving in the centre without spreading the gauge, the concrete being rarely properly set before this is done. The Author therefore prefers to use tie-rods.

is the large and solid bearing on the concrete, which is boxed in, and the fact that it is almost impossible for water to find its way under the sleeper. There is no appreciable wear between rail and sleeper, and, as they break joint, a rail-joint rarely works loose, even when heavy locomotives are employed, because the rail has a continuous solid bearing on the sleeper at the joint, and for 3 feet 6 inches beyond it. The rails can be readily renewed without disturbing the sleepers, and, being of a light section with a narrow flange, are easily raised with the crow-bar. This can be done without any tendency to twist, as is common with the heavier sections having broad flanges.

Girder-Rails.

The girder-rail system of tramway permanent way is the most modern, and, excepting the last-mentioned, the only one in the Author's knowledge that has given practically successful results where locomotives have been used. The girder-rail is now rolled in sections varying from 35 lbs. to 105 lbs. per lineal yard. The lighter sections are usually laid with a substructure of timber, iron, or steel sleepers, on a foundation of ballast or concrete. The heavier sections, however, are mostly laid on a bed of concrete, their flanges (from 5 to 7 inches wide) being relied on for a base or footing. This is in most cases sufficient, provided the rails have a thorough bearing throughout the entire width of flange, and the concrete is made with good Portland cement. Lias-lime concrete is not advisable.

Besides varying in weight, the rails differ considerably in form. *Figs. 19* to *34* represent some of the sections used in this country, on the Continent, and in the Colonies. *Figs. 19* to *24*, weighing from 40 lbs. to 68 lbs. per yard, show sections adopted in conjunction with longitudinal or cross-sleepers of wood or steel; while *Figs. 25* to *35*, weighing from 68 lbs. to 100 lbs. per yard, are usually laid on a bed of concrete.

All these rails are put together with fish-joints; but, with the exception of those used on rails under 5 inches in height, the fish-plates have been much too light. Some of these rails, moreover, are rolled to such a section as to greatly decrease the efficiency of even a heavy fish-plate. This will be understood by reference to *Figs. 30*, *31*, and *33*. These sections have the angle between the shoulders of the head and the web of rail too great, and

there is consequently no effective fish-bed. This is a most serious defect, as the head of the rail acts as a wedge which is driven down between the fish-plates each time a load passes over the joint, overcoming all the spring or vertical camber in the fish-plates.

In the majority of loose joints, the Author has found most of the fish-plates flat, with no camber, or with the camber reversed, and

Fig. 19.

Fig. 20.

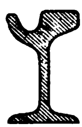


Fig. 21.

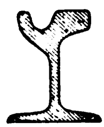


Fig. 22.

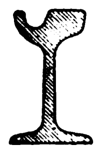


Fig. 23.

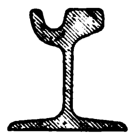


Fig. 24.

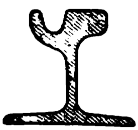


Fig. 25.

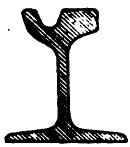


Fig. 26.

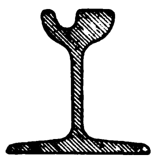


Fig. 27.

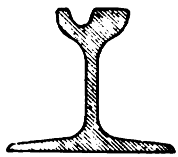


Fig. 28.

Fig. 29.

Fig. 30.

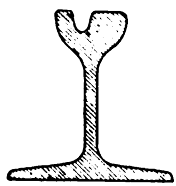


Fig. 31.

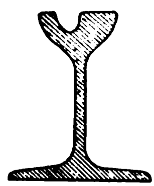


Fig. 32.

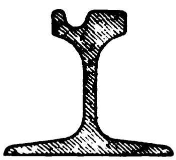


Fig. 33.

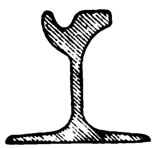


Fig. 34.

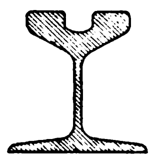
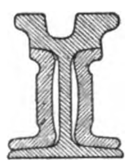


Fig. 35.



dangling loose, only hung by the bolts as in B, *Fig. 36*. With such sections, it has been customary to use fish-plates only $\frac{7}{16}$ inch in thickness, which is out of proportion to their height even if they had a good bed.

To overcome this weakness, a fish-plate with flanges has been adopted similar to that shown at A, *Fig. 37*. If the weakness had

an increase in thickness they are no stiffer vertically. They seem to increase the liability of the fish-plate to slip on its bed. With this type where $\frac{1}{8}$-inch camber was on the plate, the Author has screwed up the bolts ($\frac{7}{8}$ inch in diameter) till the spring was overcome, and the plates both touched the web of the rail (B, *Fig. 37*).

Another defect, in an exaggerated form, possessed by these last three sections, results from the tread of the rail being outside the centre of the web, and consequently the weight being carried down the outside of the web. This induces a tendency in the rail to cant or tilt to the outer side, and thereby to loosen the joints of the paving next the rail.

Fig. 36.

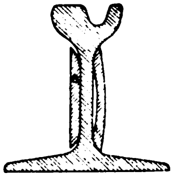


Fig. 37.

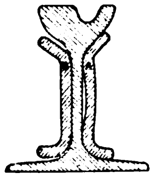


Fig. 38.

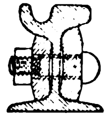
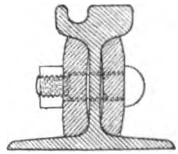


Fig. 39.



Figs. 34 and *35* are in use on the Continent. Under ordinary circumstances they have no point in their favour, as compared with a common girder-rail, and many points against them. In the Author's experience a fatal and almost invariable defect is in the lightness of the fish-plates, and this defect is, in most modern sections of girder-rails, intensified by the large angle of the shoulders, which, in many cases, affords no bed whatever under the rail-heads.

Figs. 38 and *39*, two sections suggested by the Author, avoid, to a great extent, this large angle at the shoulder, and provide a bed with a square thrust for about one-half the thickness of the fish-plates. The latter are better proportioned in their depth and thickness, and are sufficiently rigid to prevent buckling, and secured with bolts of relative strength. *Fig. 38*, a section of a rail about 56 lbs. per yard, is to be used with longitudinal or cross-sleepers, for a country or foreign line, where macadam, 4-inch cubes, or shallow random paving is to be put down. It is $4\frac{1}{2}$ inches deep and has a 4-inch flange. The web is $\frac{3}{8}$ inch thick, the fish-plates are $\frac{3}{4}$ inch thick, fastened with $\frac{7}{8}$-inch bolts, with rounded heads, square necks and nuts. *Fig. 39*, the section of a girder-rail of about 86 lbs. per yard, is intended for a first-class line, laid on a bed of concrete. It is 6 inches deep, has a 7-inch

flange, and is $\frac{7}{16}$ inch thick in the web. The advantage of a 7-inch flange is doubtful, as the great width is apt to cause the rail to twist under the crowbar, but it is generally considered that the extra bearing on the concrete outweighs the facility of crowing with a flange only 6 inches broad. The fish-plates are 1 inch thick, and the bolts are similar to those shown in *Fig.* 38, but 1 inch in diameter instead of $\frac{7}{8}$ inch.

In both these sections, there are square fish-beds, under the heads and on the flanges, and the tread of the rail extends to the inside of the web, the entire thickness (or horizontal area) of which thus carries the weight.

POINTS.

As regards the material for a tramway point, the hardest is the best if, at the same time, it has sufficient toughness to withstand the blows to which it is subjected. Chilled iron is generally used, and, if the chill is deep enough, this is certainly the hardest of all the different forms of iron; but this very quality is inseparably combined with brittleness. Consequently, the lips forming the inside of the groove, and the fine tailing out of the tongue or frog, in the open points, are soon subject to fracture where locomotives are employed. Owing to this brittleness, it is hardly possible to have a fish-joint with a chilled-iron point, as, it being necessary to cast the point to the section of the rail so that the fish-plates may fit, it reduces the sectional area too much for chilled cast-iron. To overcome this difficulty, in the Rochdale tramway, the half-length of the fish-plates were cast into the heel and toe of the point. This caused considerable extra labour in fitting and fishing the rails, the fish-plates being slightly out of position. The objection to this, however, was in the extra amount of work necessary to replace a point. The whole rail fished to the toe of the point, and the paving on each side of the rails and point had to be lifted for a distance of about 34 feet; then the point, after the running-in rail was lifted, had to be driven out towards the toe until the fish-plates at the heel were clear of the rail. The fitting in of the new point was a still more tedious process. However, it involved only about one-half the cost of renewing a crossing. On the tramway mentioned, between thirty and forty chilled-iron points and crossings have had thus to be replaced, owing to fracture of the frog or lip, and the company is now substituting cast-steel points in their place.

It is softer than chilled iron, but is also considerably tougher; and the Author has never known a sound cast-steel point to be fractured under traffic, even when of the true section of the rail, and joined to it by an ordinary fish-joint. This desirable quality of toughness generally carries with it the disadvantage of softness, though this has varied greatly in degree. According to the Author's experience, even among points in the same consignment from the same foundry, some will cut like lead under the chisel, and others chip like cast metal. Assuming it possible to rely on the hardness being equal, there is great uncertainty as to the result of the annealing process, as it is almost impossible to prevent the points from warping or twisting. This also occurs, to a certain extent, in cooling after casting.

In built-up points, made from the rolled Bessemer-steel rail, the steel is generally uniform in temper, and harder than annealed cast-steel, unless it has been manufactured purposely to undergo the unnecessary test of a falling weight. The Author has never known a rail to be fractured at the lip or elsewhere, after having been laid, though a very few have failed under crowing, when weakened by punched holes in the flange, which has ordinarily been a narrow one. He considers this material more durable than chilled cast-iron, or annealed cast-steel. Where open points are used, built-up points are superior to all others; but built-up loose tongue or drop-points would be too costly.

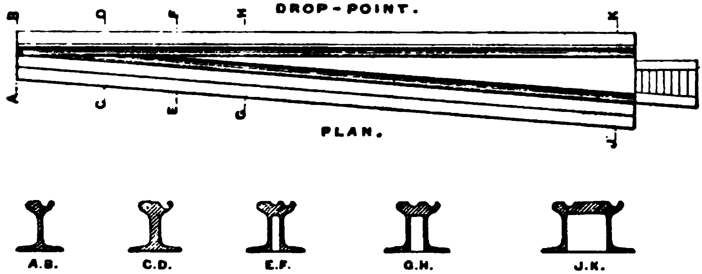
In a line where the turn-outs have a straight run-in, and horse traction is used, open points are the best, as they are safe and do not shake the cars like drop-points. Besides, built-up points can easily be made with the turn-out side curved, thus practically overcoming the angle between the running-out line of the point, and the single line. They have ordinary fish-joints like the rails, and, at the heel ends, the two rails may be made to break-joint; thereby greatly lessening the tendency to rock.

For steam tramways, it is necessary, for safety, to have either a drop or an automatic point, in each pair of rails. The full-sided fixed, or dummy point, now known as the drop-point, ***Figs. 40***, was the first used, and up to this time is by far the most general. It may be briefly described as an ordinary open point, with the running-out groove gradually sloping up to nearly the level of the rolling surface of the point, and the running-in groove the full depth throughout. This point, when new, acts very well; but with a frequent service, worked by heavy locomotives, the Author has known of many cast-steel points, and some of chilled iron, which

have worn out in six months, and become ordinary open points, through the running-out groove wearing to the depth of the wheel flanges. This is a serious objection; but another, not less so as regards cost, consists in the injury to the locomotives and cars caused by the simultaneous lateral and vertical blows to which the wheels are subjected on leaving a turn-out. The only way of lessening the lateral blow is to have the running-out groove of the point curved, so as to make a true tangent of the straight run-in; but this is seldom done.

To avoid the vertical drop, several automatic points have been

Figs. 40.



designed. The first of any practical importance was designed by Mr. C. E. Winby, *Figs. 41.* It has a tongue which forms the bottom of the running-out groove, and which has a vertical motion. The tongue is kept up to the level of the rolling surface, either by the spring of the tongue itself, or by a spiral spring under it. This point is made as a left-hand one, so that, when the locomotive or car is running into the turn-out, the tongue is inside the flange of the left-hand wheels, and is therefore less likely to be disturbed by the wheels in running in. In its normal state, this point appears like a drop-point; but, when the engine runs out of the turn-out, the flanges of the wheels press down the vertical tongue, and the tread of the wheels remains on the rolling surface of the point. Thus the desired object of avoiding a drop is gained.

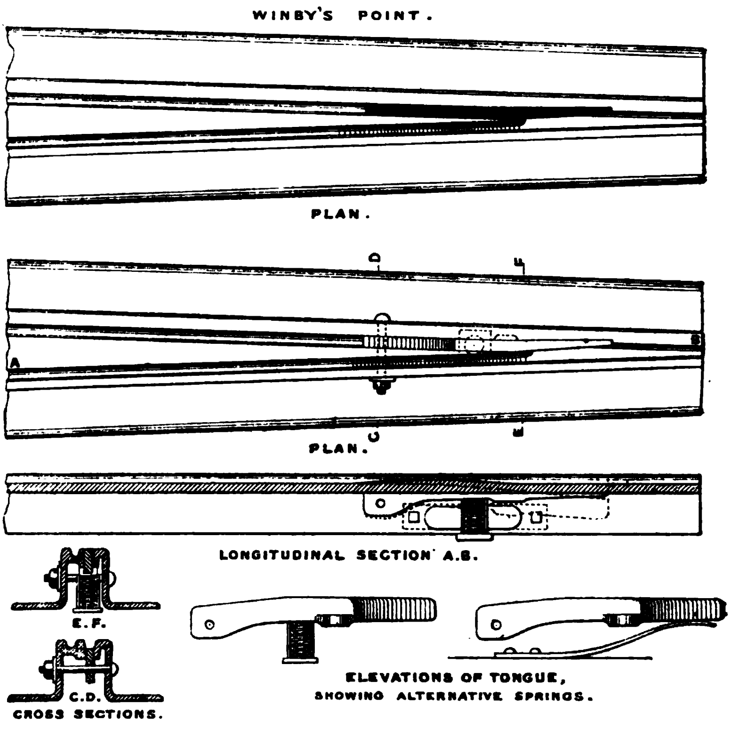
Chapman's point, *Figs. 42*, is the same as the last in principle; but, instead of a spring, a weighted lever keeps the tongue in its normal position.

The drawback to these two varieties of automatic points is the probability of the flanges of the wheels, in entering the turn-out, pressing down the tongue by mere friction, and so sending the engine on the wrong line. This is more likely to happen with the

locomotive-wheels than with those of the car, as with the former there is more lateral motion. Indeed, in several cases, where the turn-outs had a straight run-in, with a drop-point only partially worn, the Author has known the engine to take the wrong road, while the car has remained on the right one.

On the Rochdale steam-tramways, the Chapman point has been abandoned, and an old-fashioned type adopted; namely, an ordinary

Figs. 41.



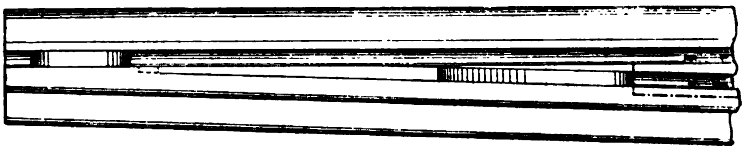
loose-tongued point, with the tongue kept to the right by a spiral spring. The left-hand road is thus always open except when a car is running out of the turn-out. In that case, the flange of the wheel wedges over the tongue against the spring, which throws the tongue back into its original position as soon as the wheel clears the toe of the point. The substitution of this spring for the piece of rubber generally used by stablemen has earned for this point the name of Marshall's Patent, *Figs. 43.* The action is simple and

effective; but it is doubtful whether the rubber is not preferable, as being cheaper, more easily replaced, and perhaps more reliable than the spring.

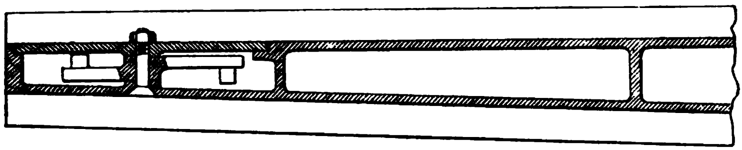
The most useful and effective automatic point, in the Author's

Figs. 42.

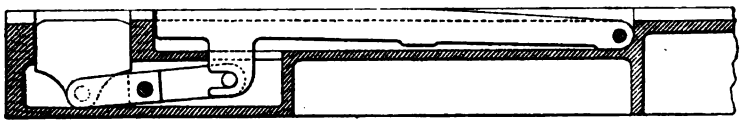
CHAPMAN'S POINT.



PART PLAN.



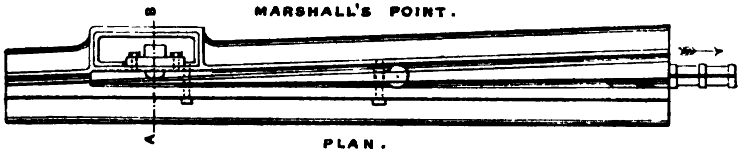
HORIZONTAL SECTION.



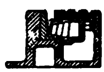
LONGITUDINAL SECTION.

Figs. 43.

MARSHALL'S POINT.



PLAN.



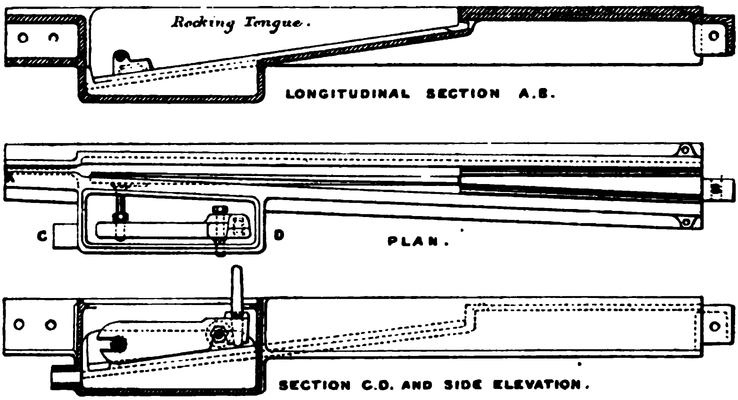
SECTION A.B.

opinion, is that of Mr. Joseph Kincaid, M. Inst. C.E., *Figs. 44.* It combines all the advantages of an automatic point, with those of an ordinary loose-tongue point. The tongue is 7 inches deep at the toe, where it is thinnest; and instead of having a vertical or lateral movement, it is arranged so as to rock or tilt, as the car

passes out of the turn-out. When at rest, the tongue completely closes the running-out line, and it is impossible, under ordinary circumstances, for the engine or car to take the wrong road. The right-hand, or running-out road, can be opened by a small lever carried on the car which fits into a socket in the counterbalance in the switch-box. It acts like, but more easily than, an ordinary switch-lever, as it has merely to tilt the deep tongue, instead of moving it over bodily. The space between the sides of the point-box and the tongue is wider at the bottom, so that loose stones are not liable to get jammed therein. The bottom of the box is also inclined towards the toe of the tongue to facilitate stones rolling that way into the switch-box. In running out of the turn-out, the

Figs. 44.

KINCAID'S POINT.

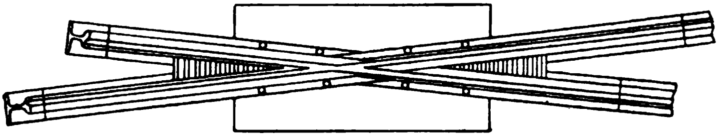


flanges of the wheels open the point by tilting the tongue into the running-in groove with the least possible friction. Mr. Kincaid has recently improved the design of this joint, whereby it can be used, 1st, as an automatic point closing the right-hand road; 2nd, as an automatic point closing the left-hand road; 3rd, as a facing point closing either road.

All crossings, whether on a steam or horse tramway, should be built of the rail used on the line, and should have the running-through rail 10 to 12 feet long, and the crossing rail 8 to 10 feet, so as to break-joint (*Fig. 45*). They should have a $\frac{1}{4}$-inch base-plate under, and extending 2 feet on each side of, the crossing. The flanges of the rails should be riveted to this, and roughened

cast-iron or steel filling-pieces bolted in the angles of the rails. This type of crossing has been used extensively, and the Author

Fig. 45.



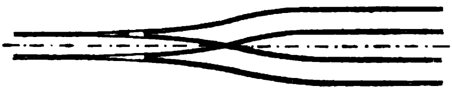
has never known one to be loosened, even where locomotives have been running over it for three or four years.

Passing-Places.

A matter of considerable importance in laying a single line of tramway is the form of the turn-outs or passing-places, which, until recently, did not receive much attention on the part of engineers.

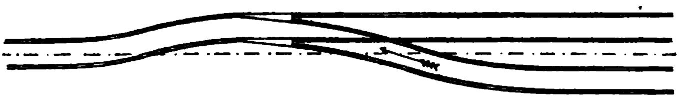
The first turn-out was symmetrical, similar to ***Fig. 46***, and was used on tramways worked by horses; the points were open,

Fig. 46.



and the run-in exactly bisected the angle of the points. The half-angle being so small, it was easy to take either road, by causing the horses to pull slightly in the required direction. The drawback of this form of turn-out is the uncertainty always present as to which road the car will take, even when pulled over by the horses. When the car is heavily loaded, and, if one rail is lower than the other, the car inclines towards the low side and takes that road. To overcome this uncertainty it became necessary to give the car a straight run into the proper road, and this was first done by laying the turn-outs as shown by ***Fig. 47***. This reduced

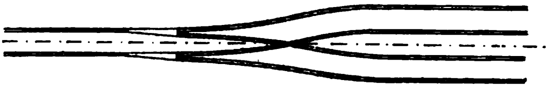
Fig. 47.



the chances of the car taking the wrong road to a minimum, but it has serious faults. Thus it involves an S curve on the single line,

just before it joins the points, which was necessary, because the single line has to be brought from the centre, to allow the double line of turn-out to be also in the centre of the road. Moreover a car running out of the turn-out, as shown by the arrow (*Fig. 47*) is transgressing the rule of the road, to the great danger of any vehicle going in an opposite direction, especially at night, when the rails cannot be seen. A lesser defect is the great wear of the rolling-stock caused by running round the small curves in leaving the turn-outs, and then back on the single line to the centre of the road. In the best form of turn-out (*Fig. 48*), the points are laid so that there is a straight run in to the proper road, and the turn-out is practically symmetrical so far as the curves are con-

Fig. 48.



cerned. The whole angle of the points is certainly thrown on the running-out road, but this is unavoidable with a straight run in. The single line running into the centre of the turn-out necessitates an S curve on both the running-in and running-out line, but they are easy curves compared with those of *Fig. 47*. The most important advantage, however, is that the car is never on the wrong side of the road.

Tie-Bars.

All systems of tramway permanent way need tie-bars, if only to prevent spreading of gauge while paving and ramming. Of these there are several kinds. Perhaps the oldest is that which ties the rails from the centre of the web as in *Fig. 49*. They are usually of $1\frac{1}{2}$-inch by $\frac{1}{2}$-inch bar-iron, drawn to a $\frac{3}{4}$-inch bolt at each end, with two nuts, and are fixed on edge so as to come between two courses of setts. The advantage of these ties is cheapness, but they are a source of inconvenience in paving, as at every tie-bar there is a closing course to put in, and consequently a variation in the width of the joints; or, a whole course of setts to cut as closers. Then again the joints enclosing the tie-bars are always wider than the others. The inconvenience with the paving is increased in curves and turn-outs, the difficulty being to get the paving to radiate in courses exactly to suit the tie-bars. There are also a

great many holes to drill or punch in the web of the rail, and with this tie-bar it is possible for the rail to cant so that the web is off the plumb, and, consequently, the whole of the rolling surface of the rail not in use. A more expensive, but perhaps better, tie-bar (*Fig. 50*), is fixed under the flange of the rail; but this must be a comparatively rigid bar, and the Author prefers a small channel-bar with clips. For the Rochdale steam tramways

Fig. 49.

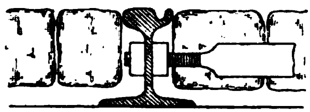
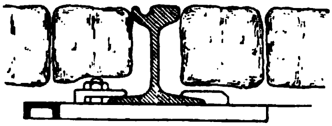


Fig. 50.



Mr. J. W. Newton used a similar bar; but instead of channel-bar, he adopted 2-inch angle-bar, with a steel liner riveted to it underneath the flange of the rail. This type of bar facilitates paving, and lessens the liability of the rail to cant, provided the clip bolts are thoroughly screwed up. The objection to this tie-bar, besides expense, is that, unless special care be taken to bed the setts properly over the clips and bolts, they are apt to work loose and rock.

In the newer sections of the Glasgow tramways, Messrs. Johnstone and Rankine use sawn timber sleepers, which act principally as tie-bars, the concrete being thoroughly packed under the rail flanges between the sleepers, so that the rail has a continuous bearing alternately on the concrete and on the sleepers. This is a successful system with horse traction, but more expensive than the last, there being only half the number of bars, as their purpose is to tie the rails only. Cross-timber sleepers, in conjunction with girder-rails, were used in 1879 by Mr. Thomas Floyd in the construction of the Croydon and the Northampton tramways.

Paving.

In the construction of a first-class tramway in this country, the paving is a most important consideration. The first element is the kind of stone to be adopted. The qualities most desirable are those that combine the maximum durability with the minimum of slipperiness. An endeavour will be made to estimate the qualities of a few of the commonest varieties of stone used for paving setts, commencing with the hardest.

Some varieties of whinstone may be considered, the hardest of the stones in common use, though others are softer than any granite, except, perhaps, Dalbeattie. Whinstone is of a dark greenish colour, much closer grained than granite, very heavy, and dresses very well. The chief objection to whinstone setts is their slipperiness in dry weather. Owing to their fine, close grain, they become glazed, or superficially engrained, with the iron from horses' shoes and wheel tires, and in dry weather the setts are dangerously slippery. In wet, the iron is probably partially oxidized, and washed off, when the surface of the stone again "bites." Thus whinstone affords a bad foothold for horses in dry weather.

Guernsey granite varies in grain, some of it being almost as fine or close as whinstone. It is a bluish grey stone, so durable that it is now commanding a preference over all other granites where the traffic is severe. It is not so slippery as whinstone, still it does not afford so good a foothold as some of the coarse-grained granites. It dresses almost as well as whinstone, and is not so heavy. Leicestershire bastard granite is not quite so close in grain as whinstone, but assimilates more to the finest Guernsey in this respect. It is of a reddish brown colour, is about equal to Guernsey granite in durability, but is, perhaps, rather more slippery. Like Guernsey granite and whinstone, it is readily dressed, and is of about the same specific gravity as the latter. These close-grained, bastard granites, are generally heavier than the coarse-grained ones, but are more easily dressed. Leicestershire coarse-grained granite is similar in grain to Peterhead and other true granites, and is of a pink colour. It is not quite so lasting as the coarser-grained Guernsey granite, is about the same as regards slipperiness, and is somewhat lighter.

Aberdeen granite is of close grain and grey colour, and, like the last mentioned, is very durable; but Aberdeen is superior to Leicestershire, or any other durable granite, for a good foothold, and is, if anything, not so heavy. This is an excellent stone for the streets of towns.

Pwllheli is a Welsh granite, with similar grain to Leicestershire, and of a light greenish colour. It is probably not so durable as Aberdeen granite, but makes an excellent paving for the less busy streets of a city or town, as it never becomes slippery. It is also a comparatively light stone.

Dalbeattie is, perhaps, the softest of all granites, very coarse-grained, of a crumbly appearance, and of a light grey colour. It is not slippery, and makes good paving for a suburban road where there is not much heavy traffic.

Millstone grit is found in the Chorley district of Lancashire. It is a coarse-grained bastard sandstone, the outside and top rock being of a yellowish colour, while the inside is blue and more homogeneous. This stone is softer than Dalbeattie granite; but, as it affords the best of all footholds for horses, it makes excellent paving for a country line.

Blue Lonkey stone is quarried in the Whitworth, Facit, and other districts in Lancashire. It resembles York stone in character, but is harder and occurs in thicker strata. It is a durable material for a country line, and is second only to millstone grit for a good foothold. Blue Lonkey is suitable for suburban lines between the rails, with granite setts in the margins.

Close-grained granites and Lonkey stone can generally be squared with a few strokes of the hammer; but true granites and millstone grit require a certain amount of "nidging" after such squaring, as they do not break so cleanly. Even after this "nidging," setts of these stones are delivered with the top surface tolerably square, but with "bellies," or bulging sides.

It is necessary now to refer to the sizes of setts used in paving work in connection with tramway permanent way. The depth of rail to be laid of course rules that of the setts, which latter should be quite an inch less, but the breadth remains to be determined. This, so far as the harder setts are concerned, is either 4 inches, or 3 inches, other breadths being uncommon. Setts of the latter size afford a better foothold, from the fact of the joints being more numerous. The Author, however, has found 4-inch setts quite as safe, making better work, and needing less repair. Probably this arises from their being better dressed with much fuller bottoms. They are also more suitable for wide joints in the paving. Lonkey and millstone grit setts may be used up to 5 inches or 6 inches wide.

There ought to be very little "camber" in paving between the rails, $\frac{3}{4}$-inch in a line of 4 feet $8\frac{1}{2}$ inches gauge being sufficient. For this gauge a width of 18 inches of paving outside the rails is enough; but for a line of 3 feet 6 inches gauge on a macadam road, there should be a margin of 2 feet 3 inches of paving outside the rails; since, if merely an 18-inch margin is laid, it has to carry all the traffic on the outermost joint of the setts, which is the weakest part of the paving.

It is a common practice, where the roads are macadam, to tooth or quoin the outer edges of marginal paving. But this, in the Author's opinion, is a mistake, as it is more difficult to keep the macadam up to the level of the paving, and the wheels of

ordinary vehicles consequently drop from each long tooth on to the next, thereby tending to loosen the setts.

Grouting.

This is done with pitch and oil, Portland cement, or blue-lias lime. For a tramway, the first is the best if properly run, just under boiling-point, at the correct temper in dry weather. The joints should first be racked, or filled with pea-gravel which has passed through a ½-inch riddle, and stopped at a ¼-inch. The paving should then be beaten or rammed, and the tempered pitch run in hot, to within ½ inch of the top of the setts. It ought not to be "topped" up, but covered over ½ inch thick, with sandy pea-gravel, which lessens the chance of the grouting melting during hot weather. The haunches of the rails should not be plastered with cement, but should be allowed to fill with the pitch as it is run into the paving. In hot weather the pitch should be tempered very soft, or it may become brittle in frost and pulverized with the traffic. Where, for economy, cement or lime grouting is used, it is better to pave with coarse-grained setts, as with these the cement has a rougher surface to hold, and has a greater chance of remaining tight. Such cement, or lime grouting, should be in the proportion of not less than 1 part of cement or lime to 2 parts of clean sharp sand.

Wood Paving.

In many provisional orders, it is stipulated that tramways shall be paved with wood in front of churches, schools, halls, &c., extending beyond the frontage for about 50 lineal yards on each side. Of the woods in common use, none is more suitable for tramway paving than seasoned beech. This should be thoroughly creosoted, and grouted to within ¼ inch of the top of the setts with properly-tempered pitch grouting. After the grouting has set, the paving should be covered ½ inch deep with sandy gravel, which has passed through a ½-inch screen. The wood setts should be creosoted; not necessarily for the antiseptic properties of the creosote, but to prevent, as far as possible, the wood from swelling after laying, by making it comparatively watertight. It also promotes the adhesion of the pitch grouting to the wood blocks, making the joints tighter and more impervious to surface water.

With cement grouting the creosote prevents the cement from getting the slight hold of the wood which it would otherwise take. The Author considers pitch far superior to cement for grouting, as the joints, besides being tighter, are more elastic and yielding, if the setts should swell in wet weather. This swelling, though not common with creosoted beech paving, is unavoidable with ordinary deal blocks. In one instance, creosoted deal blocks were used, grouted with cement. The gauge of the line was 4 feet $7\frac{1}{2}$ inches, the rail a 75-lb. girder one, with $1\frac{1}{2}$-inch by $\frac{3}{8}$-inch tie-rods 9 feet apart. After two or three days' rain the paving became saturated, burst all the tie-rods, and spread the gauge of the line to 4 feet 9 inches. It is doubtful whether pitch grouting could, with spongy deal blocks, have prevented such results, but probably it might have lessened them.

Designing a Line.

The first point to consider is whether the line should be double, or single, with turn-outs or sidings. In the majority of cases of course the single line would be the cheaper, but there are some instances where it would not. The Tramways Act of 1870 enacts that all lines shall be laid in the centre of the road, and that the rails shall not, for a distance of over 30 feet, be within 9 feet 6 inches of the face of the curb-stone. When these conditions cannot be complied with, owing to the road being too narrow, such narrow places are to be described and marked on the Parliamentary plans when applying for a provisional order. In almost all schemes there are such narrow parts of the road, and, where the ordinary traffic is not great, the company is generally allowed to lay one rail 9 feet 6 inches from one curb, and leave the distance of the other rail from the opposite curb, whatever the width of the road will allow. In other cases, the line has been laid with one rail within 2 feet of one curb, to allow a greater distance than 9 feet 6 inches between the other rail and the opposite curb. This is not advisable, as the line has to be laid to the level of the existing road, which in all cases should have a crown, or cross camber; and, in most narrow roads, this lowers the rail nearest to the curb so much under the other that it is dangerous, from the liability of the car to slip off into the channel. The Author has known cases where there was a difference in level of from 3 to 5 inches between the two rails in a gauge of 4 feet $8\frac{1}{2}$ inches. If a single line be laid along the side of a road, the cars must necessarily be, while going in one direction, on the

Set III.—Table V.—Forgings suddenly chilled from 572° Fahrenheit (300° Centigrade) to 32° Fahrenheit (0° Centigrade), and tested at the latter Temperature. Average Mean Force of Concussion in Tons.

Number of Blows from Commencement.	No. 63.	No. 63.	No. 82.	No. 89.	No. 90.	No. 55.	No. 67.	No. 74.	No. 76.	No. 86.	No. 64.	No. 65.	No. 70.	No. 54.	No. 59.	No. 60.	No. 121.
1	41·00	41·00	49·00	41·00	49·00	49·00	41·00	41·00	41·00	41·00	44·64	44·64	49·00	41·00	61·00	49·00	41·00
2	35·29	35·29	37·92	35·29	41·00	35·29	35·29	35·29	35·29	35·29	37·92	37·92	41·00	35·29	41·00	41·00	35·29
3	41·00	41·00	Broken	41·00	Broken	37·92	44·64	41·00	37·92	Broken	44·64	44·64	49·00	41·00	44·64	69·57	35·29
4	37·92	Broken	..	37·92	..	37·92	41·00	41·00	Broken	..	Broken	41·00	44·64	41·00	41·00	54·33	35·29
5	Broken	..	..	69·57	..	41·00	49·00	Broken	..	..	..	Broken	49·00	49·00	49·00	49·00	41·00
6	..	..	..	49·00	..	41·00	Broken	..	..	..	..	..	Broken	Broken	Broken	44·64	37·92
7	..	..	..	Broken	..	Broken	..	..	..	..	..	..	..	..	..	Broken	35·29
8	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	35·29
9	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	35·29
10	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	37·92
																	Contd.
Total concussions .	5	4	3	7	3	7	6	5	4	3	4	5	6	6	6	7	46
Total deflections between bearings in inches . .	$3\frac{3}{16}$	$2\frac{3}{8}$	$1\frac{7}{16}$	$4\frac{1}{4}$	$1\frac{3}{8}$	$4\frac{5}{8}$	$3\frac{11}{16}$	$3\frac{1}{8}$	$2\frac{7}{16}$	$1\frac{5}{8}$	$2\frac{3}{16}$	$2\frac{15}{16}$	$3\frac{5}{16}$	$3\frac{1}{4}$	$3\frac{5}{16}$	$3\frac{11}{16}$	$38\frac{3}{16}$
Total mean force . .	155·21	117·29	86·92	273·78	90·00	242·18	210·93	158·29	114·21	76·29	127·20	168·20	232·64	207·29	236·64	307·54	1648·26

Average total mean force = 261·93 tons. Average total deflections = 7·91 inches.

observed by Chernoff, as a result of chilling), but at the same time considerably reduces both the elongation and contraction of area at fracture.

The effect of impact after the sudden chilling of metals is, however, a different matter, and the Author's experiments have substantially demonstrated that a sudden chill very materially reduces the resistance of metals to impact.

It may be stated that one hundred and forty-two forgings, weighing in all 15 tons 5 cwts., and about 60 tons of snow, ice, and salt for the freezing mixtures required to produce the low temperatures, were used in these experiments.

The Paper is accompanied by two sets of photographs and a diagram.

[APPENDIX.

APPENDIX.

SET I.—TABLE I.—FORGINGS GRADUALLY COOLED FROM 100° FAHRENHEIT TO 0° FAHRENHEIT, AND TESTED AT 0° FAHRENHEIT.
AVERAGE MEAN FORCE OF CONCUSSION IN TONS.

Number of Blows from Commencement.	No. 168.	No. 170.	No. 172.	No. 174.	No. 176.	No. 178.	No. 85.	No. 98.	No. 103.	No. 108.	No. 111.	No.
1	61·00	61·00	61·00	61·00	54·33	54·33	61·00	54·33	54·33	61·00	61·00	54·
2	49·00	49·00	49·00	49·00	49·00	44·64	49·00	49·00	49·00	41·00	49·00	54·
3	54·33	49·00	54·33	49·00	44·64	49·00	54·33	54·33	49·00	44·64	49·00	49·
4	54·33	49·00	54·33	44·64	44·64	44·64	49·00	49·00	44·64	44·64	61·00	49·
5	54·33	49·00	54·33	44·64	49·00	44·64	49·00	49·00	44·64	44·64	61·00	49·
6	54·33	49·00	54·33	44·64	54·33	49·00	54·33	49·00	44·64	44·64	61·00	49·
7	54·33	49·00	54·33	49·00	54·33	44·64	54·33	49·00	44·64	44·64	54·33	54·
8	61·00	49·00	54·33	Broken	49·00	44·64	54·33	49·00	44·64	44·64	49·00	54·
9	69·57	54·33	54·33	..	49·00	44·64	54·33	49·00	Broken	49·00	49·00	61·
10	61·00	54·33	49·00	..	49·00	44·64	54·33	49·00	..	44·64	61·00	61·
	Contd.	Contd.	Contd.	..	Contd.	Contd.	Contd.	Contd.	..	Contd.	Contd.	Con
Total concussions .	69	52	13	8	86	24	16	23	9	15	16	18
Total deflections between bearings in inches	$35\frac{7}{8}$	$28\frac{11}{16}$	$6\frac{7}{8}$	$4\frac{7}{16}$	$54\frac{7}{16}$	$15\frac{5}{16}$	$8\frac{3}{8}$	$13\frac{9}{16}$	$5\frac{1}{4}$	$9\frac{7}{16}$	$8\frac{11}{16}$	9
Total mean force .	3951·23	2781·65	642·66	341·92	4087·89	1062·51	800·33	1095·94	375·53	642·00	801·30	922

The sectional distortion from circular form at point of fracture resulting from the continued concussions is given under:—

	No. 168.	No. 170.	No. 172.	No. 174.	No. 176.	No. 178.	No. 85.	No. 98.	No. 103.	No. 108.	No. 111.	No.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.						
Maximum, diametrical reduction . .	..	0·69	0·69	..	1·39	0·69						
Maximum, diametrical increase . .	1·39	0·69	..	0·69	0·69	0·69						

SET I.—TABLE II.—FORGINGS SUDDENLY CHILLED FROM 100° FAHRENHEIT TO 0° FAHRENHEIT, AND TESTED AT THE LATTER TEMPERATURE. AVERAGE MEAN FORCE OF CONCUSSION IN TONS.

Number of Blows from Commencement.	No. 167.	No. 169.	No. 171.	No. 173.	No. 175.	No. 177.	No. 85.	No. 98.	No. 103.	No. 108.	No. 111.	No. 9
1	69·57	69·57	61·00	69·57	61·00	49·00	61·00	61·00	54·33	61·00	61·00	61·
2	54·33	54·33	49·00	54·33	49·00	49·00	44·64	49·00	44·64	44·64	49·00	49·
3	54·33	54·33	49·00	61·00	49·00	49·00	49·00	54·33	44·64	49·00	54·33	49·
4	61·00	54·33	49·00	54·33	49·00	49·00	49·00	54·33	44·64	49·00	49·00	49·
5	61·00	54·33	Broken.	54·33	54·33	54·33	54·33	54·33	44·64	49·00	61·00	54·
6	61·00	54·33	..	54·33	54·33	49·00	54·33	54·33	44·64	49·00	49·00	49·
7	61·00	54·33	..	54·33	54·33	49·00	49·00	54·33	49·00	54·33	49·00	54·
8	54·33	54·33	..	49·00	49·00	54·33	Broken.	54·33	49·00	54·33	49·00	54·
9	61·00	54·33	..	Broken.	54·33	49·00	..	49·00	49·00	54·33	Broken.	54·
10	61·00	54·33	..	..	54·33	49·00	..	49·00	49·00	49·00	..	54·
..	Contd.	Contd.	..	..	Contd.	Contd.	..	Contd.	Contd.	Contd.	..	Con
Total concussions .	16	13	5	9	14	26	8	40	15	13	9	23
Total deflections between bearings in inches . . .	7¾	6 9/16	2 3/8	4 3/8	7½	14 13/16	4 3/16	22 13/16	9 1/16	7 3/16	4 11/16	12
Total Mean Force .	891·57	673·90	208·00	451·22	691·66	1294·33	361·30	2046·99	665·15	616·97	421·33	1148·

The sectional distortion from circular form at point of fracture resulting from the continued concussion is given under:—

	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.						
Maximum diametrical reduction . .	..	0·69	..	..	0·69	..						
Maximum diametrical increase . .	1·39	..	1·39	1·39	0·69	1·39						

Set II.—Table III.—Forgings gradually cooled from 212° Fahrenheit to 0° Fahrenheit, and tested at the Latt
Temperature. Average Mean Force of Concussion in Tons.

Number of Blows from Commencement.	No. 148.	No. 150.	No. 152.	No. 154.	No. 156.	No. 158.	No. 160.	No. 162.	No. 164.	No. 166.	No. 180.	No. 182.	No. 184.	No. 186.	No. 66.
1	61·00	49·00	49·00	49·00	49·00	49·00	61·00	49·00	49·00	49·00	61·00	81·00	61·00	69·57	54·33
2	41·00	41·00	41·00	35·29	35·29	35·29	41·00	37·92	41·00	41·00	49·00	61·00	44·64	44·64	49·00
3	37·92	37·92	35·29	44·64	31·00	35·29	41·00	37·92	41·00	44·64	61·00	81·00	49·00	44·64	49·00
4	41·00	37·92	37·92	35·29	31·00	41·00	41·00	35·29	41·00	41·00	61·00	61·00	44·64	44·64	44·64
5	41·00	37·92	37·92	35·29	33·00	41·00	37·92	35·29	41·00	41·00	49·00	61·00	49·00	44·64	49·00
6	41·00	37·92	Broken	35·29	33·00	41·00	37·92	35·29	41·00	44·64	61·00	61·00	44·64	44·64	44·64
7	41·00	37·92	..	35·29	33·00	41·00	41·00	35·29	41·00	49·00	61·00	61·00	49·00	44·64	49·00
8	41·00	35·29	..	35·29	41·00	41·00	41·00	35·29	37·92	49·00	49·00	61·00	49·00	44·64	44·64
9	41·00	Broken	..	37·92	37·92	35·29	41·00	35·29	37·92	49·00	54·33	81·00	44·64	44·64	44·64
10	41·00	..	..	37·92	37·92	35·29	41·00	35·29	37·92	44·64	61·00	61·00	44·64	44·64	44·64
11	Contd.	..	..	Broken	Contd.	Contd.	Contd.	Contd.	Contd.	Contd.	Contd.	Contd.	Contd.	Contd.	Contd.
Total concussions	76	9	6	11	59	27	13	110	36	22	32	30	95	15	20
Total deflections between bearings in inches	50	$6\frac{5}{16}$	$3\frac{7}{8}$	$8\frac{3}{16}$	$45\frac{3}{4}$	$19\frac{11}{16}$	$8\frac{13}{16}$	$96\frac{3}{8}$	$29\frac{11}{16}$	$14\frac{1}{16}$	$15\frac{11}{16}$	$14\frac{11}{16}$	$59\frac{3}{8}$	$9\frac{3}{8}$	$12\frac{3}{16}$
Total mean force	3505·56	314·89	201·13	381·22	2293·54	1065·74	509·48	3833·30	1283·18	965·72	1886·42	1769·00	4579·32	649·84	910·15

The sectional distortion from circular form at point of fracture resulting from the continued concussions is given under:—

	No. 148.	No. 150.	No. 152.	No. 154.	No. 156.	No. 158.	No. 160.	No. 162.	No. 164.	No. 166.	No. 180.	No. 182.	No. 184.	No. 186.	No. 66.
	Per cent.	Per cent.	Per cent.	Per cent	Per cent.	Per cent.	Per cent	Per cent.	Per cent.	Per cent.					
Maximum diametrical reduction	1·39	1·39	0·69	..	0·69	0·69	..	1·39	..	0·69					
Maximum diametrical increase	1·39	0·69	0·69	1·39	0·69	0·69	0·69	0·69	0·69						

Set IV.—Table VI. *continued.*—Forgings Suddenly Chilled from 1,112° Fahrenheit (600° Centigrade) to 0° Fahrenhe[it] (– 18° Centigrade), and tested at the latter Temperature. Average Mean Force of Concussion in Tons.

Number of Blows from Commencement.	No. 67.	No. 76.	No. 86.	No. 89.	No. 82.	No. 65.	No. 70.	No. 74.	No. 99.	No. 115.	No. 101.	No. 107.	No. 106.	No. 104.	No. 102.
1	37·92	42·74	51·53	44·64	42·74	39·40	42·74	44·64	44·64	51·53	Broken	41·00	44·64	46·71	46·71
2	Broken	35·29	37·92	37·92	Broken	34·10	Broken	39·40	Bro n	4 6·71	..	35·29	44·64	Broken	46·71
3	..	37·92	35·29	36·56	..	34·10	..	37·92	..	41·00	..	41·00	46·71	..	42·74
4	..	Broken	37·92	Broken	..	34·10	..	Broken	..	Broken	..	44·64	39·40	..	41·00
5	..	..	44·64	..	..	36·56	..	..	..	..	..	44·64	49·00	..	46·71
6	..	..	Broken	..	..	Broken	..	..	..	..	..	Broken	Brokn	..	[41·00
7	..	..	..	..	..	..	..	..	..	..	..	..	..	..	44·64
8	..	..	..	..	..	..	..	..	..	..	..	..	..	..	41·00
9	..	..	..	..	..	..	..	..	..	..	..	..	..	..	46·71
10	..	..	..	..	..	..	..	..	..	..	..	..	..	..	42·74 Contd.
Total Concussions .	2	4	6	4	2	6	2	4	2	4	1	6	6	2	14
Total Deflections between bearings in inches	$\frac{13}{16}$	$2\frac{13}{32}$	$3\frac{25}{32}$	$2\frac{11}{32}$	$\frac{23}{32}$	$4\frac{11}{32}$	$\frac{23}{32}$	$2\frac{9}{32}$	$\frac{11}{16}$	2	..	$3\frac{1}{4}$	$3\frac{7}{16}$	$\frac{21}{32}$	$9\frac{3}{16}$
Total mean force. .	37·92	115·95	207·30	119·12	42·74	178·26	42·74	121·96	44·64	139·24	..	206·57	224·39	46·71	566·61

Average total mean force = 98·73 tons. Average total deflections = 1·50 inch.

was it a matter of simple memory, for it would be equally impossible for any one to recollect the logarithms, to eight places, of hundreds of thousands of numbers.

It was, however, founded on a power of memory, of a more limited range. Mr. Bidder's process may be said briefly to be this: having stored in his memory the logarithms of a few simple numbers, he was able, by his wonderful skill in dealing with figures, to make use of them, mentally, to calculate accurately the logarithms of any other numbers however large. A brief description will give an idea of the manner in which this was done.

In the first place, as to the mnemonic bases used. He knew by heart the logarithms of a great many *small prime numbers*, nearly all, he said, under 100, and some few above.

Secondly, it will be easily understood that these would enable him to calculate the logarithms of any large numbers which were multiples of those he knew. Thus for the logarithm of 63 he had only to add together the logarithms of 7 and 9; for the logarithm of 3567, he had only to sum up the logarithms of 29, 41, and 3, and so on.

In carrying out this process he had an almost miraculous power of seeing, as it were intuitively, what factors would divide any large given number not a prime. Thus if he was given the number 17,861, he would instantly remark it was $= 337 \times 53$; or he would see as quickly that 1659 was $= 79 \times 7 \times 3$. He could not, he said, explain how he did this, it seemed like a natural instinct to him.

These two qualifications, therefore—the knowledge of the logarithms of certain small primes, and the power of reducing large compound numbers to their component factors—constituted the foundation on which Mr. Bidder's operations proceeded. They would suffice for determining the logarithms of a great many numbers by simply adding together the logarithms of their component factors, which he could do mentally with the greatest ease.

But it still remains to be explained how he treated the case of large primes, and this is really the great interest of his process.

His first endeavour was to find some multiple number *very near* the number given, differing from it only in the last place of figures, and if possible only by unity. For example, being given the number 1051, he would easily find the logarithm of 1050 ($= 30 \times 7 \times 5$) to which he would then have to make an addition for the difference of 1. This addition would be very important (for the accuracy aimed at), as it would affect the last five figures

of the logarithm. The operation is difficult and complicated, and the manner of dealing with it was really the key to Mr. Bidder's success. It is due to him, therefore, to explain it somewhat fully.

His method consisted in the use, as a basis, of the following Table, which he knew by heart (only seven places are given here, he himself used eight):—

For an Addition to any Number n of		There must be added to its Logarithm.
$\frac{n}{100}$	. . . .	Log. 1·01 = 0·0043214
$\frac{n}{1000}$	. . . .	Log. 1·001 = 0·00043407
$\frac{n}{10000}$	. . . .	Log. 1·0001 = 0·0000434
$\frac{n}{100000}$	. . . .	Log. 1·00001 = 0·0000043

Suppose therefore, as in the above case, there is to be added to the logarithm a sum corresponding to an addition to the number of $\frac{n}{1050}$ (= 1). Mr. Bidder would take the proportion $\frac{1}{1000} : 0\cdot0004341 :: \frac{1}{1050} : 0\cdot0004134$. This calculation would pass through his mind instantaneously, and thus he would get, by mental addition—

Log. 30 . . .	= 1·4771213
„ 5 . . .	= 0·6989700
„ 7 . . .	= 0·8450980
Addition for the 1	= 0·0004134
Log. of 1051 . .	= 3·0216027

But it would sometimes be necessary to add a larger proportion than above mentioned, say between $\frac{n}{100}$ and $\frac{n}{1000}$. For these he adopted mentally a kind of proportionate sliding scale. Thus, for the number 601, he would see that $\frac{n}{600}$ would require 0·0007232, so that—

Log. 600 . . .	= 2·7781513
Addition for the 1	= 0·0007232
Log. of 601 . .	= 2·7788745

sill as against 17 feet 9 inches, the minimum height at neap-tides. By an inspection of Fig. 2 the collapse can be easily accounted for. It is obvious that the foundation was deficient in strength, and that the wall was too thin. The water getting behind, saturated the back filling, reducing the angle of repose to less than 20° (as was subsequently proved by experiment), thus making the back pressure practically hydrostatic, and at the same time reducing the stability due to the dead weight of the wall. The outer toe, where the greatest weight was concentrated, was placed between the first and second rows of piles, and this, bearing on the sleepers, which were originally too thin, and had become more or less unsound, had cut through them, thus giving the final impetus to the wall. It would appear that the second and third portions, not moving quite so far, held for a longer time owing to the support given the sleepers by the second row of piles beneath.

The first thing which the Author attempted to do was to save those parts of the standing walls which were built and founded in a manner similar to the one that had fallen, and which began to yield more or less to the back pressure now that the bond was broken. He decided to pile in front of them and secure them by tie-bars, anchored in the ground some distance back.

The work was begun by driving along the breach, to the full depth of the basin-wall, a row of sheet-piles, 7 inches thick, in close contact, parallel to the river-wall and 50 feet from it. This served the double purpose of holding up the wharf, which was gradually slipping into the dock under the action of the water, and as an anchorage for the tie-bars from the river-wall. The backing was, at the same time, removed from the dock-walls to a depth of 19 feet 3 inches from coping-level, and the wall-piling then proceeded with. For this purpose, baulks of sawn pitch-pine, 40 feet long, 15 inches square, with the toes splayed inwards and shod with $\frac{3}{8}$-inch iron-plate, were driven 9 feet into the hard clay close up to the foot of the wall, 10 feet apart. Holes 4 inches in diameter had previously been bored, 7 feet down from coping-level, opposite the centre of each pile, and through these and the piles were passed $3\frac{1}{2}$-inch mild-steel jointed tie-bars, screwed with nuts at each end, and anchored 50 feet back. The nuts, rear and front, were simultaneously tightened up with large spanners, worked by eight men to each, until the heads of the piles were brought in contact with the face of the wall. By this means it was secured both at the top and at the bottom

without the employment of a second tie-rod, the fixing of which would have been a most expensive and nearly impossible operation, as the authorities were unable to permit the draining of the dock for even one tide in consequence of the number and size of the ships then in the harbour. The stretch of wall eastward of the fallen part was also in rather an unsound condition, although it had been partially rebuilt some years ago, and it was therefore tied to the river-wall running parallel with it. The anchorage for each pile of the north-west wall consists of two piles, each 22 feet long and 15 inches square, braced 6 inches apart in the clear and driven at a distance of 50 feet from the wall-face; a timber washer, 4 feet 12 inches by 12 inches, being placed behind, and the end of the tie-rod passed through it and between the buried piles.

All the old back-filling was replaced by a mixture of builders' rubbish, clinkers, and spent lime from the gas purifiers, which formed a compact, semi-solid mass a few weeks after it was laid. The result of these operations has been most satisfactory. In one of the walls secured in this manner, the outward bulge disappeared under the tension of the tie-rods, aided by the water-pressure on the face at spring-tides, before the back-filling was replaced.

The Rebuilding of the Walls.

During the month of April following the failure, a number of borings were made in front of the fallen wall, and at the back of the grillage. Three trial-pits were sunk through the grillage, by the aid of cast-iron casings, to the hard clay and the borings continued by rods until the rock was reached. In this operation a special form of auger, combining the screw and cylinder gouge, was used with good effect. From the information so obtained, the Author designed the wall section and mode of founding shown in Fig 5, Plate 9. It was proposed to drive the old bearing-piles 4 or 5 feet further into the hard substratum; to drive in front a row of toe-piles, 15 inches thick for the entire length, with paving 12 feet wide outside, at the level of the hard clay; to excavate the clay and mud round the heads of the old piles to an average depth of 4 feet, and to fill in with concrete composed of 6 parts of broken limestone, 2 parts of sand, and 1 part of Portland cement, and upon this foundation to raise the new wall. This idea had to be abandoned on the ground of expense, as the total amount found to be available for securing 850 lineal feet of walls in the manner already described and for reconstructing

himself to strengthening the old foundation and raising the best form of wall that circumstances permitted. This is being done in sections in the following way:—

A coffer-dam (Fig. 3, Plate 9) was erected enclosing the debris. It consisted of two rows of piles 40 feet long, and 12 inches by 10 inches, 5 feet apart, driven 10 feet into the ground, with stiff clay puddle rammed between. The foot of the dam inside was strengthened by a counter-dam filled with the excavated rubbish, back-filling, &c., removed from the enclosed space. The whole was stayed indirectly from the shore. Provision was made at each end for flooding the dam in case of a threatened collapse. The leakage heretofore has been comparatively slight, coming chiefly from ground springs and "blow-holes," and it can generally be kept under by one 8-inch "Gwynne" pump to every 200 feet of dam, working two or three hours a day of ten hours. It was found that ground-leaks and "blow-holes" within the coffer-dams could be temporarily isolated by means of cast-iron hollow screw-piles driven a short distance into the hard clay, the water being allowed to rise in the pipe. After a time however, the water under the pressure of the column in the pipe found its way round the foot of the pile, but not as freely as when the spring was open.

When all the water was expelled the grillage was cleared and taken up. The whole piles were tested by ramming with a 40-cwt. "monkey," and if found to be firm and sound were allowed to remain, but if defective in any way they were replaced by pitch-pine piles; the heads were dressed off and a new lot of beech sleepers, 15 inches by 12 inches, spiked down on them. The grillage was then relaid, a good deal of the old material being worked in for the purpose. A row of pitch-pine toe-piles, 23 feet long and 14 inches square, spaced 4 inches apart, at a batter of 1 in 4, were next driven to a depth of 13 feet 6 inches into the hard clay. The pile shoes used were diamond-pointed and weighed 57½ lbs. each. Chisel-pointed shoes had been tried at first but although entering the hard clay more freely, the piles twisted considerably and were not so easily kept in position while being driven. The driving was done by a 45-cwt. "ram" falling from 8 to 10 feet. Any pile which did not move half an inch after fifteen blows of 12 feet height of fall was considered as fairly driven. To the toe-piles at the level of the grillage was fastened, by ¾-inch bolts, a pitch-pine waling, of 12 inches by 10 inches scantling, scarf-jointed and running the entire length. Outside this was placed an iron waling, 6 inches wide, 1¾ inch thick at the centre,

and 1 inch thick at the edges, with 2¼-inch holes drilled at every 6 feet of its length, the joints being fish-plated. Flat bar-iron ties, with one end bent for 9 inches, and the other end, for a length of 16 inches, forged round and screwed, were passed through the walings and spike-bolted to the new grillage platform, the bent end serving as an anchor. The heads of the toe-piles were next sawn off horizontally, and a top sill, 15 inches wide, fixed on them by ¾-inch bolts; the concrete was laid for the entire length to the level of the top sill, "displacers" not exceeding 1½ cwt. each, or more than 2 feet 6 inches high, being embedded one-half in the upper surface, while good stiff clay puddle was pitched 1 to 1 and rammed in front to the tops of the toe piles. These operations completed the new foundations proper (Fig. 4, Plate 9).

The face of the new wall starts flush with the outside of the top sill, and has a batter of 1 in 6 to within 13 feet of coping level where the ashlar masonry facing begins. So far, and for a depth of 3 feet from the surface, the wall consists of fine concrete, composed of 1 part of Portland cement, 2 parts of sand and fine gravel, and 2 parts of small broken stones. The main body of the wall, as well as the backing to the ashlar work, is also of concrete, the component parts being 1 of Portland cement, 2 of sand and 3 of broken stones (macadam size). "Displacers" were used up to the level of, but not beyond, the bottom of the ashlar work; they are placed not less than 3 feet apart and the same distance from the wall face. All the concrete was hand-mixed and well turned over before being sprinkled with water, which was carefully but not too freely added. The mass was then shovelled into iron hoppers holding 6 tons each and deposited by the steam crane. Each layer was completed and rammed for the entire length before the succeeding one was commenced; no layer was more than 3 feet or less than 2 feet in thickness.

The wall section was shaped by wooden shutters of 3-inch stuff, planed and coated with soft soap inside.

All the old ashlars were recovered and re-dressed ready for setting, while the lower portion of the wall was being built.

The back-filling was not commenced until the expiration of fifteen days after the completion of the wall to coping level.

The Paper is accompanied by several drawings, from which Plate 9 has been prepared.

(*Paper No. 2434.*)

"The Sidhnai Canal System."

By Loudoun Francis MacLean, M. Inst. C.E.

(*Abstract.*)

About 15 miles above its junction with the Chenab, the River Ravi flows for 8 miles in a nearly straight channel called the Sidhnai Reach, the width of which is 450 feet at the upper end, and about 1,200 feet at the lower end near the town of Serai Sidhu. The Sidhnai Canal head-works are about 3½ miles above this point, and the canal, which is on the left bank, flows nearly south-west for 37 miles, passing under the North Western Railway near Rashida, 21 miles from Multan. The surveys were made early in 1883, and the excavation was commenced in January 1884, the whole canal, Rajhahas and main water-courses being completed and in operation in June 1887. The area commanded by the Sidhnai Canal is 429 square miles, for which the calculated discharge is 1,072·5 cubic feet per second, at the rate of 2·5 cubic feet per square mile; this land, before the commencement of the works, was nearly all uncultivated. The main canal, where it leaves the Ravi, has a bed 80 feet wide, and is designed for a full supply of 6 feet depth of water, with a bed-slope of 1 in 8,000. The other main channels of the system are from 10 to 20 feet wide, according to the area commanded, and are from 4 to 5 feet deep, the bed-slopes being from 1 in 2,500 to 1 in 5,000.

On account of the small amount of water in the Ravi, at times when it is required for irrigation, it was found advisable to construct a dam, for which purpose the French needle system seemed best suited, and after some trouble from sudden floods this was completed in April 1885. A lock was subsequently provided on the same system to enable boats to pass up or down the river when the water was headed up.

The following details as to the working of the needle dam are given. The needles are made of deodar wood, and are 7 feet 6 inches long by 5 inches by 3½ inches, with a stout handle 18 inches long, ending in a knob; they weigh 36 lbs. dry

and 40 lbs. wet, and can be manipulated by one man. After placing the needles in position at first, they are forced up close together by a man standing on the pitching below the dam, who inserts a crowbar with a wedge-shaped end into the openings, causing the needles to slide along the face of the crest wall, any leakage between them being stopped in the following way. A basket, fixed to a bamboo about 10 feet long and filled with shavings or chopped straw, or some similar substance, is slipped down in front of the leak, so that the light material may be sucked by the current into the opening, which it effectually closes. It was not found that the shock of closing on the crest wall, when first placing the needles in position, ever caused them to break when the wood was sound.

When there is a great difference of level between the water above and below the dam, the rush of water through the interstices makes it very difficult for a man to stand on the pitching below and use a crowbar. This difficulty is overcome in the following way: a piece of tarpaulin or oiled canvas, 8 feet long and 6 broad, is fastened at one end to a wooden bar 6 feet 4 inches long, with handles at each extremity, and at the other end to a bar of round iron, 6 feet 4 inches long and 1 inch in diameter. It is then rolled upon the iron bar, and placed horizontally against the needles, above where the excessive leakage occurs, and the wooden bar, which remains on the outside of the roll, is either tied or held in position by the handles; the roll is then let go, and the weight of the iron bar causes it to unroll itself down the face of the needles, at once closing all the leaks. In order that the screen may be more easily recovered, a cord is attached to a loose collar at each end of the iron bar, and when the needles have been closed up, the screen is pulled up from the bottom by these cords.

For the purpose of regulating the height of water above the dam, it is sufficient in most cases to push some of the needles forward at the top, the water escaping through the open spaces left in this way; but should it be necessary to provide for a greater flow, a sufficient number of them are removed altogether; this can generally be done by hand, but if they have "jammed" from any cause, or if the pressure of the water against them is too great, they are lifted by means of a bent lever.

An eye-bolt is attached to each needle just below the handle; this serves as a fulcrum for the extracting lever, and also to fasten tackle to when the pressure is too great for the needles to be drawn forward by hand. It was found dangerous to work them from the beams, which are only 18 inches wide, and after

one life had been lost, and the Author himself had had a narrow escape, a foot-bridge was added to the dam. This foot-bridge consists of two flat-bottomed rails of 60 lbs. to the yard, 3 feet apart, with 3-inch planking between them, the rails being kept together by tie-bars, and fastened down to the piers at each end by 1-inch iron rods imbedded into the masonry. To lessen the upward shock of the waves during flood-time, the planking is perforated with a large number of 1-inch auger-holes. It is proposed to have two small trollies running on the rails of the foot-bridge, to facilitate the removal and carriage of the needles. The dam is 733 feet long, and the actual cost of it was Rs. 1,01,000, or £7,863 at the current rate of exchange, being about £10 7*s.* per lineal foot.

Arrangements have been made to send warnings by telegraph of any rise of 1 foot in the Ravi at Madhopur and Lahore during twenty-four hours. As floods take a minimum of five days from the former, and two days from the latter place to reach Sidhnai, these warnings have been of the greatest service.

The rules for working the dam, sanctioned by the Chief Engineer, are to the following effect:—

I. The level above the dam at which the water is to be kept by opening or removing needles, is fixed from time to time by the Executive Engineer, the usual height being 6·5 feet above the crest wall of the dam, *i.e.*, 1 foot below the top of the beams, giving 5·5 feet of water in the canal.

II. Anything above 12·5 feet at Bakrola, or 9 feet at Shadera, is to be considered a flood.

III. On a flood being telegraphed, the needles are to be removed one day before it can arrive, so as to reduce the depth of water above the dam to 6 inches above the full supply required in the canal at the time.

IV. As the river begins to rise on the approach of the flood, the needles are to be removed gradually.

V. As soon as the river begins to fall, the needles are to be replaced, so as to raise the water again to 6·5 feet, unless there is intimation of another flood coming, in which case only sufficient needles need be put in to raise the water 6 inches above the supply required in the canal at the time.

VI. When the surface of the river below the dam is at the height fixed in Rule I, all the needles are to be removed.

VII. If it should be necessary for training the river, or removing silt from in front of the canal-regulator and below the lock, to put in needles when the water below the dam is higher than stated in

Rule I, written instructions must be obtained from the Executive Engineer.

VIII. Care must be taken that the dam beldars (native labourers) shall regularly remove floating rubbish from against the needles; and during the flood season, the head-works subdivisional officer must inspect the dam at least once every day.

IX. To prevent deposits in front of the canal-regulator, and above and below the lock, the needles should be distributed so as to force a strong current on to those places; soundings are to be taken every three days along certain lines, and any serious accumulations reported to the Executive Engineer.

X. Soundings are to be taken weekly, and on the subsidence of each flood, along the line of crates at the toe of the pitching of the dam, and any serious scour is to be at once reported. Pitching-blocks should be thrown into the hole scoured out, if the depth continues to increase.

XI. The head-works subdivisional officer will be responsible for maintaining the supply in the canal to the officer in charge of the Sidhnai canal subdivision, and shall not raise the supply without written orders from him or from the Executive Engineer, but may lower the supply on receiving intelligence from any canal servant of an accident having occurred to a canal, or if the state of the head-works requires him to do so. In such cases, however, he is at once to report his reason for so doing to the Executive Engineer and the officer in charge of the Sidhnai canal subdivision.

The success of the scheme has been greater than was anticipated. In the Administration Report of the Canals in the Punjaub for the years 1889–90, it is stated that "the Sidhnai Canal shows a profit of 15·82 per cent., against 12·61 per cent. in 1888–89, and 13·84 per cent. in 1887–88; this canal maintains its character as a highly remunerative work."

The Paper is accompanied by a map and sixteen plates, which have been published in the "Selections from the Records of the Government of India, Public Works Department," No. ccxlviii.

(*Paper No. 2445.*)

"Rao Shri Pragmalji Bridge, Mandvi, Kutch."

By Clement Moriscrip Sykes, Assoc. M. Inst. C.E.

Mandvi, situated on the west bank of the Rukhmavati, is the most important town and the chief seaport in the province of Kutch. It has a large shipping trade with Zanzibar, the Persian Gulf, and the Indian Coast, but the inland traffic was until recently much impeded for want of a bridge. The Rukhmavati, like most Indian rivers, is nearly dry in the fair weather; but to cross it, even at that time of the year, is a work of great labour both to man and beast, as the bed is composed entirely of sand to a depth of from 6 to 12 feet. At high-water the cart-tracks are covered, so that it was necessary, in the absence of other means of transit, either to await the falling of the tide or make a long detour over the sand, and during the monsoon floods it was simply impassable.

The State, under the Presidency of Colonel A. M. Phillips, obtained the loan of the services of Mr. W. S. McClelland, M. Inst. C.E., from the Jamnagar State, in Kathiawar, and he, at the request of the Council, made a survey, and submitted designs for a bridge, of the following description:—

	Feet.
Twelve segmental arches with a span of	44·00
Versed sine	5·50
Radius for intrados	46·75
Radius for extrados	58·92
Depth of keystone	2·00
Voussoirs at springing	3·00
Height of piers	15·00
Thickness of piers	6·00
" of abutment	14·00
Width of roadway	20·00

The total length of the bridge, including wing-walls, was 694 feet, and this was made up as follows:—

Twelve arches, 44 feet	528
Eleven piers, 6 feet	66
Two abutments, 14 feet	28
Two wing-walls, 36 feet	72
Total	694

The highest flood observed was in 1884, when there was a depth of 17·79 feet of water under the arch at the east abutment. The banks of the river near the town are not well defined, more especially on the western side. The bed, as has been already mentioned, is sand, and below this there is a stratum of indurated clay, locally called "muram," which forms in some places a conglomerate of considerable firmness, and in others a sort of clay sandstone.

The work of the bridge was originally commenced under the guidance of the State Engineer, but it being thought advisable to have European skill and supervision on a work of such importance, Mr. McClelland, Engineer-in-charge of Harbour Works, was asked to take the work under his care, and the Author being then on the spot as assistant to the Engineer-in-charge, Harbour Works, Mandvi, was appointed Superintendent of Works. The Author had great difficulties to contend with. He not only had to see the works carried on, but at the same time to manage three different quarries—at considerable distances from one another and from the site of the bridge—for the stone required. Great endeavours were made to get contractors for material, but Kutch not possessing many men experienced in dealing with such large quantities, and the few there were banding themselves together, the Author was compelled to have the quarrying done by the department.

The stone used for foundations, piers, abutments, backing, spandrel and wing-walls, was a littoral concrete sandstone of very coarse grain—like sandstone grit. The nearest quarries were situated on the coast about 12 miles from Mandvi; but as the earliest month during which they could be worked was September, and no stone could be got after the setting in of the west winds in the beginning of March, it was found imperative to seek in other places, and the quarry ultimately chosen was the one at Kutri, 24 miles east of Mandvi, as the crow flies. This being up the Gulf of Kutch, is protected, so that the boats were able to ply till late in the season. The average quantity of stone brought in per month was 4,000 cubic feet. It was conveyed in boats, and thrown out about a mile from the site of the bridge—excepting at spring tides—and was then transported to the works by a light tramway on the river-bed. Besides the sandstone, a kind of yellow trap had to be worked for the arch-stones, parapet-walls, and cornice. It was obtained from a quarry at Ondote—a village under one of the Bhayats of the Rao—14 miles to the N.W. of Mandvi. There were no properly constructed roads to the place, which made it very difficult for the bullocks to drag the carts across

country with blocks weighing from 1,100 to 3,700 lbs., such as were required for the voussoirs at the haunches and skew-backs. The total quantity of stone quarried was 68,534 cubic feet, and the cost, landed at the work, was Rs. 50·75 for 100 cubic feet. Lime was also made departmentally. It was burnt in a flare-kiln and cost Rs. 19 4a. per 100 cubic feet.

While the stone and the other material was being got together, the excavations for the foundations were steadily progressing, and between November, 1883, and the middle of June, 1884, all the piers and the abutments were finished and left during the monsoon. An unprecedented flood from an abnormal rainfall of 64·95 inches[1] necessitated raising the piers 3 feet. The turning of the arches was commenced on the 17th of January, 1885, and on the 21st of May of that year, the last centering was struck. This gives an average of 10½ days for each arch, setting and removing, centering and fixing ahead for the next; but as the first took a longer time than the others, owing to the men being new to the work, the average may fairly be taken as 9 days for each arch. The foundations at the western abutment were 9 feet in sand, and 9 inches in muram, and the depth increased from this until at the eastern abutment they were 8 feet in sand and 6 feet in muram. To keep the water out of the last six piers and the abutment was a work of considerable difficulty; and a centrifugal pump, delivering 1,000 gallons per minute, had to be worked continually. The foundations up to the water-level—namely, a depth of 14 feet at the eastern abutment—were built in Portland-cement mortar in the proportion of 1 to 5. The piers are 15 feet from low-water level to the springing course, and 6 feet wide, the cut-waters being formed of starlings disposed along two sides of an equilateral triangle having the pier for its base. The masonry is rusticated block-in-course, with 1-inch chisel draft. The arches are of the yellow trap from Ondote, solid fine-dressed ashlar with $\frac{3}{16}$-inch joints. The impost, cornice and parapet wall is also of same stone, all fine-dressed.

The arches were turned on timber centering, of five ribs each; four sets were used to enable the work to be pushed on more rapidly for fear of floods. There were, however, none above the ordinary level that year, although some were sufficiently high to

[1] It is said that Kutch is visited by an extraordinary rainfall once in a cycle of forty years, but as there are no statistics going back so far as 1844, the validity of this assertion cannot be refuted. The average rainfall from 1848 to 1853 for Kutch is 12·59 inches. At Mandvi it is about 15 inches; so that the above fall is more than four times the usual amount.

have damaged the works had they not been finished betimes. The centering was supported on five trestles, with posts 8 or 9 inches in diameter; these were all braced together by diagonals and made as stiff as possible; over each set of uprights was a pillar-plate 10 inches by 5 inches, extending right across the arch and supporting, by means of cast-iron sand-boxes, the five ribs. To prevent the whole structure from settling into the sand a sill-plate 10 inches × 5 inches was fixed between the uprights; and at each point of support, all the loose sand being dug away, large flat stones from 3 to 4 feet square were placed so as to distribute the load. This was found to be fairly firm, but it had to be wedged up occasionally by wedges put between the stone and the sill-plates —as spring tides always caused a slight amount of movement. The centres were struck as soon as the key-stone was placed in position, and the ultimate average settlement of all the arches did not exceed $1\frac{1}{4}$ inch.

The cost of masonry, arching, parapet and cornice, is given in Appendix I; and the cost of centering per arch in Appendix II. The bridge was declared open for traffic on the 19th of January, 1887, by H. E. Lord Reay, Governor of Bombay.

The Paper is accompanied by four tracings, and two pen-and-ink sketches.

[APPENDIXES.

APPENDIXES.

Appendix I.

			Rs.	As.	P.
283,076	cubic feet	excavation for foundation	8,322	8	5
43,219	„	filling	13,193	7	0
108,148	„	superstructure, sandstone	25,568	11	11
3,078	„	impost cornice, and caps of cutwater of Ondote stone	2,779	3	6
37,000	„	arching—Ondote stone	40,605	14	11
11,767	„	backing	2,394	3	3
16,968	„	cornice and parapet of Ondote	15,694	11	7
Centering—four sets:—					
Cost, with labour for setting up, &c.			10,399	10	11
Sand-boxes			553	2	1
Road over bridge, and western approach			4,392	5	2
			1,20,609	11	3
		Contingencies	5,405	14	5
		Total rupees	1,26,015	9	5

The sandstone used in the masonry cost per 100 cubic feet, delivered on the site, Rs.10 9a, and the Ondote quarry stone per 100 cubic feet, Rs.50 12a. The lamps and lamp-posts with fixing cost an additional Rs.3,419 3a.

Appendix II.

	Rs.
Cost of centering, sand-box, with labour for shifting, &c., per arch	912·74
Cost per cubic foot of arch	0·295
Cost per running foot of span	20·74

(*Paper No. 2473.*)

"On the Flow of Water in Earthen Channels."

By Ralph Sadler, Assoc. M. Inst. C.E.

Numerous formulas have been designed to express the relation between the velocity of the flow of water in earthen channels and the slope and dimensions of the bed. They were collected some years ago by Mr. Thomas Higham, of the Punjab Irrigation Department, and published by him in his "Hydraulic Tables," in 1877.

By assuming a side slope of ½ horizontal to 1 vertical he was enabled to simplify greatly the use of the formula for the design of earthen channels. It is found in practice that artificial channels never retain exactly the form in which they were constructed, but gradually approximate to this form of section, and it is the practice in the Punjab to design channels expressly, so that when the slopes are covered and protected by the silt berms which always collect, they may discharge the calculated volume of water.

The chart (Plate 10) which accompanies this Paper is intended still further to facilitate the design of such channels to suit the varying conditions which occur in practice, and, indeed, it may be said to be the most useful part of Mr. Higham's Tables in a graphic form.

The old formula for the discharge of rivers and canals was of the form—

$$V = C\sqrt{R\,S},$$

where V = mean velocity,
R = hydraulic mean depth,
S = surface slope.

Different observers assigned various and arbitrary values to the coefficient C, and it was only when D'Arcy and Bazin's experiments were published that a rational theory with regard to it was suggested. Bazin found that C varied with the hydraulic mean depth of the channel according to the equation—

$$C = \frac{1}{\sqrt{0\cdot00008534\left(\frac{r+4\cdot1}{r}\right)}}$$

Curves of equal velocity have been calculated by this formula for velocities of 1·0, 1·5 .... 5·0 feet per second, and are shown on the chart by full lines. This formula gives excellent results within the limits of the experiments, and, indeed, for all ordinary conditions to which earthen channels are applicable.

Later on Kutter took up the experiments of D'Arcy and Bazin and others mentioned in his work, and devised a formula applicable to all kinds of open channels. He found that the coefficient C depended not only on the hydraulic mean depth, but also on the slope of the channel and on the degree of roughness of the bed. Bazin had provided for variations in the roughness of the bed by dividing the channels into four types.

Kutter now gave for C the equation—

$$C = \left\{ \frac{\left(41 \cdot 6 + \frac{1 \cdot 811}{N} + \frac{0 \cdot 00281}{s}\right)\sqrt{r}}{\sqrt{r} + N\left(41 \cdot 6 + \frac{0 \cdot 00281}{s}\right)} \right\}$$

where N is a coefficient of roughness, to which, in the case of rivers and canals in perfect order, he assigned the value 0·025. The curves of equal velocity given by this equation have been calculated for velocities of 1, 2, 3, 4, and 5 feet per second, and are shown on the chart by dotted lines. The calculations by this formula are much more tedious than in the case of Bazin's simpler expression, and the chart shows that within the limits of size and slope usual in practice the results differ but little from his. It is doubtless true that the coefficient varies with different degrees of roughness, &c., even in earthen channels; but the utility of the chart would be much diminished by any attempt to introduce into it additional curves, while in cases where special circumstances exist and can be allowed for, the chart may still be useful to obtain a first approximation. Observations in the Punjab show that the value of N varies considerably. These results, however, have apparently been obtained by calculating the value of N from observed discharges combined with observations of surface slope. By applying the formula in this way it is obvious that all sources of variation, such as a rising or falling gauge, direction and force of wind, and even the personal equations of the observers are collected and allowed for, and until a series of observations more careful and reliable than those utilized by Kutter in framing his equation is published, his conclusions may be accepted for practical purposes.

It is within the Author's experience that the discharge in a particular channel, with a flat slope, fell to a very low figure owing to the growth of weeds, which had to be removed at great expense.

It is not the object of the present Paper, however, to deal with such variations, but to introduce a graphic method to obviate much tedious calculation in designing earthen channels. In problems of this kind the velocity is generally limited by the nature of the soil, which will only stand a certain rate of current without being cut away, and the longitudinal slope either is indicated in some way by the conditions of the problem, or has to be kept as low as possible.

The chart is so simple as to need little explanation. The vertical scale represents the hydraulic mean depth in feet; the horizontal scale, reading from left to right, gives the length of channel for each foot of fall. Thus supposing the bed-slope to be 1 in 5,000, then the vertical ordinate through the figure 5 (counting from the lower left-hand corner) gives a scale of velocities corresponding to the various hydraulic mean depths, on the vertical scale at the side. If upon this ordinate the hydraulic mean depth of any proposed channel having the given slope is marked off, then the corresponding velocity may be readily deduced from the position of this point with reference to the velocity curves.

For instance, if Bazin's formula be followed, the velocities of such a channel corresponding to different hydraulic mean depths will be as follows:—

Velocities.	Hydraulic mean depths.
1·0 foot per second	1·55 foot
1·5 ,,	2·52 feet
2·0 feet ,,	3·63 ,,

Thus for even half-feet of velocity the hydraulic mean depth given by Bazin's formula may be read to 0·01 foot by inspection, and may be readily estimated for intermediate velocities. If Kutter's formula be preferred, the following figures are obtained:—

Velocities.	Hydraulic mean depths.
1 foot per second	1·42 foot
2 feet ,,	3·65 feet
3 ,,	6·54 ,,

In order to find the bed-width and depth of a channel to suit a given case, it is first necessary to assume a side slope. Taking

this as Mr. Higham does in his tables at 1 horizontal to 2 vertical, the curves to the right of the chart may be used.

For instance, supposing a limiting velocity of 2 feet per second to have been taken, and the corresponding hydraulic mean depth to be 3·65 as in the last example, a pencil line is ruled across the chart at this level, and from the point where it cuts the dotted curves to the right of the chart, vertical lines are drawn to the scale below, upon which the depths of water corresponding to the bed-widths selected may be read off.

Thus, omitting depths above 6 feet, the horizontal line through 3·65 gives by inspection the corresponding depths and bed-widths as follows:—

Bed-width.	Depth of Water.
14 feet	5·84 feet
16 „	5·54 „
18 „	5·25 „
20 „	5·07 „

From these figures the mean widths and areas of cross-section may be deduced, and the velocity being already assumed, the corresponding discharge may be calculated.

The following example will serve to indicate this method of using the chart, in the case of a channel with a slope of 1 in 5,000, to discharge 300 cubic feet per second, with a limiting velocity of 2·0 feet per second.

V.	R.	D.	W.	Mean width.	Discharge.	Conditions.
2·0	3·65	4·55	30	32·27	293·7	Slope = 1 in 5,000 ;
...	..	4·43	35	37·21	329·7	V < 2 feet per second ;
..	..	4·30	40	42·15	..	Discharge = 300 cubic feet per second.

The details of the calculation may conveniently be written out in the tabular form given above, where V = mean velocity; R = hydraulic mean depth ; D = depth of water; W = bed-width. The value of R is obtained by inspection from the chart, and the three values of D and W are found upon it almost as readily. Adding half the depth of the water to the bed-width gives the mean width of the channel, and this multiplied by the depth and the velocity gives the discharge. The result shows at once that, to be within the limiting velocity the bed-width must be a little over 30 feet, with a depth of 4·5 feet. The dimensions of the channel being

thus fixed approximately, the final calculations are easily made in the usual way.

The chart has been drawn out to include conditions far beyond the limits of ordinary usage, extending to slopes as flat as 1 in 20,000 and hydraulic mean depths up to 12 feet. Channels are seldom made flatter than 1 in 10,000, or with so great a depth as 10 feet. Consequently the useful part of the curves is comprised within one-fourth of the chart as drawn out, and for ordinary use the chart might be much reduced in size. It is interesting to note how closely Bazin's results agree with those obtained with Kutter's formulas for channels in perfect order. Moreover, this agreement is greatest in the part of the chart most used; viz., with a velocity of 2 feet per second or thereabout, and slopes from 1 in 4,000 to 1 in 10,000. This is not surprising, as, of course, Kutter used Bazin's experiments in compiling his formula; but it shows clearly that whatever theoretical defects Bazin's formula may have, it is applicable to all ordinary cases of artificial channels.

The communication is accompanied by a chart from which Plate 10 has been engraved.

(*Paper No. 2474.*)

"Railways and Collieries of North China."

By Claude William Kinder, M. Inst. C.E.

The most recent information communicated to the Institution on the subject of Chinese railways is contained in an abstract from a paper by Adolphe Schwarz, published in the "Wochenschrift des oesterreichischen Ingenieur- und Architekten-Vereines."[1] This account contains many errors, and is calculated to give so erroneous a view of the state of affairs, that the Author has felt impelled to write the true history of the matter.

The first systematic attempt to introduce railways into China was made in 1863, and Sir R. Macdonald Stephenson devoted considerable time to the subject at the instigation of various important firms in Shanghai and Hong Kong. A company was proposed with a view to building a line from Shanghai to Soochow, but the project fell through owing to the opposition of the Chinese officials. He then suggested that lines should be built entirely from materials manufactured in China, thus necessitating a minimum of foreign capital and interference, and it is interesting to note that the same idea has now been adopted by the Government after a lapse of twenty-seven years.

As a proof of the meagre knowledge of Chinese ideas prevailing at that time among Europeans, it may be mentioned that a scheme for a line connecting Peking to Calcutta was actually introduced to the astonished Mandarins, who then, as now, consider that any communication whatever with India would be absolutely fatal to China's welfare. It was not until 1876 that the Woosung[2] line was built, and although it was closed and torn up in October, 1877, it had done good work in demonstrating to thousands of Chinese the advantages of improved communication. The gauge of this railway was only 2 feet 6 inches, and everything

[1] Minutes of Proceedings Inst. C.E., vol. xcviii. p. 452.

[2] See the History of the Shanghai and Woosung Railway, by G. J. Morrison, in the library of the Institution (in MS.); also Rapier on the Woosung Railway, Minutes of Proceedings Inst. C.E., vol. lix. p. 274.

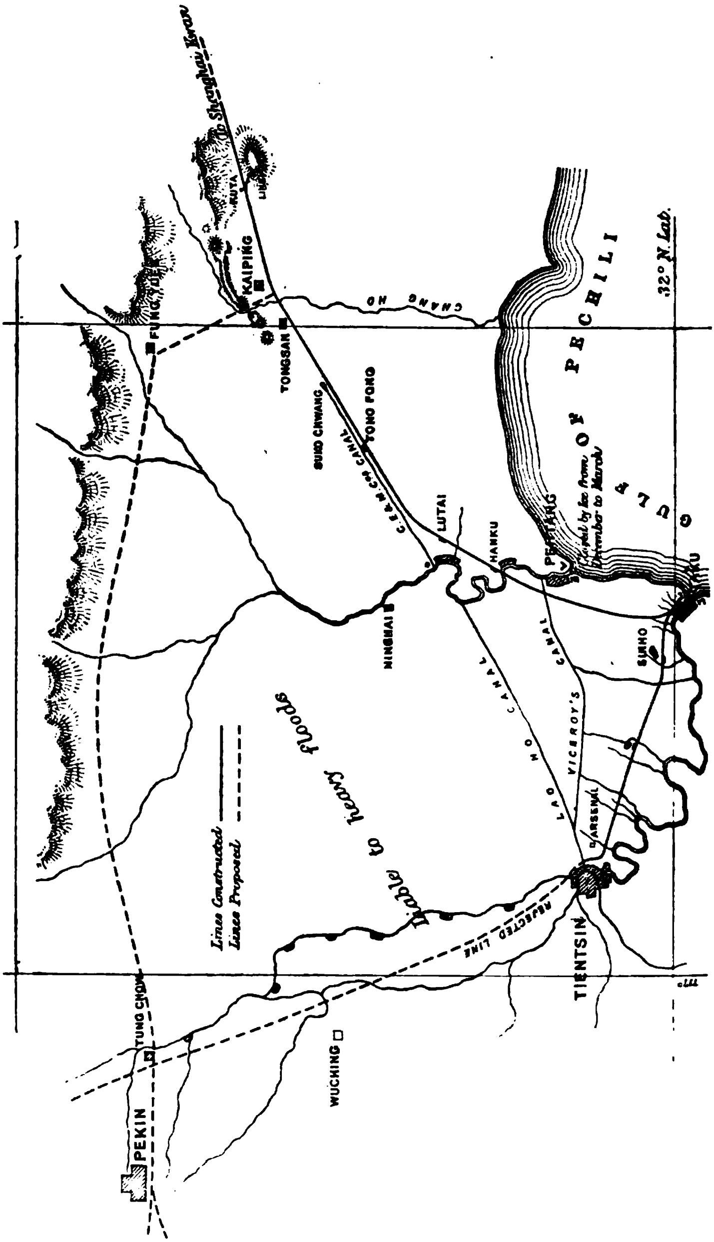
was on a small scale, owing to want of funds; but it was capable of doing solid work under the management of Mr. G. J. Morrison, M. Inst. C.E. In after years "the remains" became a serious source of trouble, as the authorities showed a desire to make use of the old engines and rolling-stock for the Kaiping line, which, if persisted in, would have caused the introduction of a gauge which the promoters of the Woosung line never intended to propose as suitable for the permanent railways of China.

While H.E. the Viceroy of Nankin was pulling up the Woosung line, the far more powerful and sensible Viceroy of the Northern Provinces, H.E. Li Hung Chang, was settling with the manager of the China Merchants Steam Navigation Company, Mr. Tong King Sing, the preliminaries for opening out a colliery for a supply of coals to the rapidly increasing fleet, to be followed by iron-works, and perhaps a railway, if it should be possible to introduce this objectionable item into the scheme.

The locality for the operations was left until a suitable expert could be obtained from Europe. On the arrival of Mr. R. R. Burnett, M. Inst. C.E., followed by Mr. J. M. Molesworth, M. Inst. M.E., with diamond rock-boring plant, several districts were examined, and in the autumn of 1878 a hole was put down at Tongsan (*Fig. 1*) some 80 miles N.E. from Tientsin. Coal of excellent quality was proved to exist there, and large quantities of inferior fuel, suitable for native use, were also met with. The best spot for a colliery was found to be at Linsi, 15½ miles further east; but as this could not be worked without a railway of considerable length, it was necessary to commence operations on an inferior site nearer the market, and it was not until 1888 that shaft-sinking was begun at Linsi, and the line to that point decided on.

The nearest navigable river to Tongsan is the Peh Tang Ho, and it was arranged to build 29 miles of railway to Lutai, an important town on the east bank. The Author then (in 1878) joined the service as Resident Engineer, to survey and construct the line; but, before any effective start could be made, orders came to stop all work, the Imperial sanction for a railway having been withdrawn. After much discussion, it was decided, naturally against the wishes of the engineers, that a canal of 21 miles should be made to connect Lutai with a point some 7 miles S.W. of the colliery site, which latter distance could be covered with a light tramway, worked by mules, as on no account would locomotives be allowed. Fully appreciating the importance of getting any line at all, the energetic director pushed on, attacked on all sides by

Fig. 1.


PEKIN
TUNG CHOW
WUCHING
TIENTSIN
ARSENAL
REJECTED LINE
LAO HO CANAL
VICEROY'S CANAL
SIKHO
NINGHAI
LUTAI
HANKU
PEHTANG
GULF OF PECHILI
Closed by ice from December to March
SUKO CHWANG
TONG FONG
C.E. & M. Co. CANAL
TONGSAN
KAIPING
FUNG YUEN
CHANG HO
To Shanghai Kwan
Liable to heavy floods
Lines Constructed
Lines Proposed
32° N. Lat.

infuriated censors, superstitious natives, and too often deserted by his friends and well-wishers.

To give an idea of the annoyances practised, the following may prove interesting. While surveying, a pole was planted on the summit of a hill where the remains of a rude fortification still exist; this was reported to the throne, and several official despatches were required before the authorities were satisfied that no serious rebellion was contemplated, or the Tongsan Earth-dragon likely to be disturbed. Again, when it was proposed, some years later, to use certain iron ores to the N.E., the whole scheme was stopped as being detrimental to the manes of the imperial dead situated about 120 miles in a totally different direction, and so great was the uproar, that the colliery itself, then in full operation, was very nearly closed. The mere sight of a few boring-rods, steam-pipes, or anything with a hole in it, drove the natives frantic with fear of rebels, and for years after they persisted in the belief that, when the time was ripe, the make-belief gas- and water-pipes would become cannon or other terrible weapons of warfare. Pamphlets were circulated accusing the engineers of attempts to unearth the treasure guarded by the dragon, and calling for the immediate destruction of the works. Strikes were common, and caused much delay, to obviate which men from other provinces were imported; but, with the exception of those from Shantung and Canton, few have remained. In spite of the constant assertion that labour was abundant, it was often impossible to secure sufficient hands, especially in the summer months when they were most needed.

The heavy machinery was conveyed to the colliery, partly by carts from Lutai, but chiefly by boats ascending the Chang Ho from the coast, a route involving many tedious transhipments amidst the deep mud and constant rain. This duty was admirably performed by Mr. Molesworth, who had to put up with exposure and hardships rarely met with, even in China. The shafts sunk were both 14 feet in diameter, lined with solid limestone blocks set in cement. No. 1 was carried to a depth of 600 feet; No. 2, serving as an upcast, to a depth of 300 feet only.

Details with respect to the blasting operations have been already communicated by the Author to the Institution.[1]

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[1] Minutes of Proceedings Inst. C.E., vol. lxxx. p 188.

The coal-bearing stratum is here some 800 feet thick, and dips at an angle of from 45 to 60 degrees. It contains thirteen seams, nine of which are worked, having a total thickness of 125 feet; only two are of good quality, viz., No. 2, which is 30 inches thick, and No. 5, 70 inches thick. The latter contains 4·54 per cent. ash, and only 0·97 sulphur.

Workings.

On account of the high dip, the workings are laid out on the French and Belgian system.

The coal is cut overhand, the miners standing on "packing" sent down to fill the gob. The rubbish and stone for this purpose is lowered from the surface by self-acting inclines. Where the seams are from 12 to 30 feet or more in thickness, special systems are in use, the coal in such cases being extremely soft, and liable to run. In thin seams of hard coal, props are set as in long wall mining, and afterwards withdrawn, allowing the roof to come down.

The packing system for high dips is certainly the safest, and as it requires little or no timber, it in many cases proves most economical. The great demand for good coal caused the opening out of dip workings in No. 5 seam to a depth of 950 feet, the water and coal being drawn by three powerful engines placed below ground, worked with steam from the surface. The Company, however, propose to use electric-motor pumps and hauling machinery driven by a dynamo on the surface.

The pumping-plant consists of two of Davey's differential engines placed on the surface, with cylinders 50 inches and 30 inches, and a stroke of 6 feet. One of these works two 20-inch lifting-sets in No. 1 shaft, and the other two 20-inch plunger-pumps in No. 2 shaft.

The Guibal fan is 30 feet in diameter by 10 feet wide, and is placed near to the up-cast shaft; at 40 revolutions per minute it passes 120,000 cubic feet of air. It is driven by a high-pressure compound engine, but has an auxiliary single-cylinder engine placed so as to be readily coupled if needed. Walker's shutter has put a complete stop to vibration, which at one time was excessive. The water-gauge is usually as low as 0·60 inch, owing to the large airways and numerous splits.

Output.

Owing to the closing of navigation during the winter, there is only a small demand for best coals at that season, but inferior coals are always saleable. The output since the commencement has been as follows:—

	Tons.		Tons.
1881	3,613	1886	187,314
1882	38,383	1887	224,705
1883	75,317	1888	241,136
1884	126,471	1889	247,867
1885	187,039		

The average cost of production at the mine is nearly 5*s.* per ton, and the selling prices average as follows:—

	Per ton.
Inferior coals at land sale	6*s.* to 8*s.*
Hand-picked best lump	21*s.*
Cobbles ,, ...	14*s.*
Dust ,, ...	10*s.*

The railway rates for coal—as indeed for everything else—are extremely low, viz., for 7 miles haul, 5*d.* per ton; for 55 miles haul, 2*s.* 6*d.* per ton; for 81 miles haul, 2*s.* 11*d.* per ton; the rolling-stock being entirely the property of the railway company.

Brick-works and Potteries.

The beds of fire-clay found in the district are of excellent quality, the best being equal to Stourbridge. The natives have several large potteries besides those belonging to the company, which, however, by the use of steam-power and superiority of site, can manufacture at lower rates. The crushing is done by a Clayton edge-runner mill and a pair of rolls, driven by a portable engine with a cylinder 12 inches by 20 inches. The bricks are rough-moulded by hand, and then pressed by portable machines. Compressed red bricks are made in sheet-iron hand-moulds, and cost 13*s.* per mil, the pressed fire-bricks costing nearly double this amount, but being of superior quality. A Chinese brick-moulder rarely turns out over four hundred bricks a day, but as his pay is only from 5*d.* to 6*d.* the cost is not excessive, although higher than in many parts of Europe.

The pottery and tiles are all of coarse types, only adapted for native use, large pots being in great demand, and forming

stream, which is at this point 800 feet wide, with a 20-foot fairway at low tides. There is also a smaller wharf at Tientsin, mostly used for native cargo and for the supply of coals to town and shipping.

Beyond four running sheds, the company has spent little money on buildings, the stations being brick or mud structures, which are quite good enough for the traffic obtained. An extensive station was laid out at Tientsin, but was stopped when the extension to Tung Chow was prevented; however, the Company wisely secured ample land at all important points.

Several cases of trains being divided and engines derailed occurred at first, but this has been entirely prevented by an apparatus which will not allow the points to be moved until a bolt in the *centre* of the track is first manipulated. The native does not care for the trains, and it is useless to try and teach a new man every few days; but he learns at a glance that he cannot meddle with the bolt in the track without certain loss of his own life; thus all further trouble and fly-shunting has been put a stop to at a trifling cost. Interlocking gear is used at the junction at Tongku; but the natives constantly steal the parts of the apparatus which are outside the cabins. So far, it has been found impossible to maintain distant signals unless a watchman resides near each, a species of blackmail being imposed by the villagers along the whole route. Owing to accidents having occurred by the destruction of a signal-arm, the Author determined to adopt the suggestion made many years ago in England—namely, that the absence of a signal-arm should invariably mean danger; the arm being raised for line clear. However serious such an alteration would prove in Europe, it was a very simple matter in China, and effectively removed a source of danger in a country of storms and ever-pilfering coolies.

The stations are connected by a telegraph worked with Morse instruments of Danish manufacture, the operators being students from the Tientsin Telegraph School, who also act as interpreters in the ticket-offices. No trains can be moved by telegraph, the staff system being rigidly enforced throughout.

Level-crossings are numerous—another evil inseparable from economical construction in flat countries. They are protected by gates and signal disks, so attached to them as to be visible to drivers for a considerable distance. The gatemen are, however, very unreliable, and no dependence can be placed on any signals after dark.

Locomotives.

The Company have in all seventeen locomotives, as follows:—

	Inches.
Two ballast engines	8 × 16 cylinders.
Two 6-wheel tank engines . . .	10½ × 18 ,, , Stephenson.
Six 10- ,, ,, ,, . . .	15 × 18, Dubs and Sharp, Stewart, and Co.
One ,, ,, ,, ,, . . .	15 × 20, Grant, U.S.
Four "American" type with tenders	17 × 24, Dubs.
Two "Mogul" ,, ,,	17 × 24, being built.

In spite of the extreme badness of the water, a considerable mileage is secured, but not without injury to the boilers; so far, steel has given results quite equal to copper for the fire-boxes; but it will require a longer trial to decide which is preferable.

The American engines were built to the same order as the six ten-wheel tank-engines, but cost considerably more. The boiler steams better than any on the line; it is of the Belpaire type, and burns more coal than the other engines doing the same work—nevertheless, it is a favourite with the drivers. The driving wheels are 48-inch, while those of the other engines have 42-inch only; but a longer stroke of piston gives the same tractive power of 10,000 lbs.

These engines were only intended to run at 20 miles per hour; but it is impossible to make the drivers keep to this, and 35 has been repeatedly reached when making time. In future, no driving wheels will be under 48 inches on the tread. The whole of this class have six drivers, with a pony-truck at each end. The tank is of saddle pattern. The engines weigh from 38 to 42 tons in working order, as some have more cast-iron than others in their wheels and other parts. They are designed for use on 45-lb. rails, and are carefully equalised throughout. The larger engines are used exclusively on the heavier track of 60 to 70-lb. rails, and it is hoped that in future no main line will be laid with anything lighter. The passenger engines have a bogie in front, with four coupled 70-inch drivers. Tenders are placed on bogies with 36-inch wheels; but in future, the ordinary freight-bogie with 42-inch wheels will be employed. All cylinders are placed outside, with the valve-chest on the top.

During winter there was much trouble with the pumps freezing up; but this has been overcome by introducing a steam-jet into the suction-pipe, as is commonly done in the United States. Several injectors have been tried, but have not given

freely used for heating. Water is too valuable to allow of the waste which often occurs in getting injectors to work, and donkey-pumps are still preferred both by drivers and their native firemen.

The average consumption of coal is 40·18 lbs. per mile, which is not at all excessive, as the quality of the fuel is 10 per cent. inferior to Newcastle coal, and the boilers are affected by the saline nature of the water supply. The trains commonly consist of from thirty to forty vehicles, carrying some two hundred passengers and 200 to 400 tons of cargo; but far heavier loads are at times taken. At present only three native and seven English drivers are employed under Mr. G. D. Churchward, Assoc. M. Inst. C.E., Locomotive Superintendent; but it is intended to utilize the foreigners chiefly as inspectors, and introduce more Chinese drivers as fast as they may be obtainable.

Traffic Department.

The train service is under the orders of the traffic manager, Mr. R. W. Lemmon, who has two English head-guards and a full staff of Chinese officers. Each train has either an English driver or guard, and in some cases both; but it is intended, if possible, to employ all Chinese drivers and foreign guards, as it is found that few of the Chinese are able to enforce proper discipline without serious opposition from their fellow-countrymen, who do not object to obeying a foreigner.

Between Taku and Tientsin the passenger traffic often exceeds eight hundred per diem; but only mixed trains are run, the speed being kept below 30 miles per hour, until some advantage can be secured by increasing it, which cannot be until the extension to Peking becomes possible. The first-class rates are slightly under two Mexican cents (=0·7*d.*) per mile, and the second-class just half this amount; a special charge is made for *coupés*, according to number of people carried. The average rate for carrying heavy goods and minerals is about 0·45*d.* per ton per mile; but varies with length of haul. All cash accounts are kept entirely by Chinese methods; the statistical branch, however, is still in the hands of the foreign staff, as its value is not appreciated by the Chinese authorities, who regard it as wasted labour.

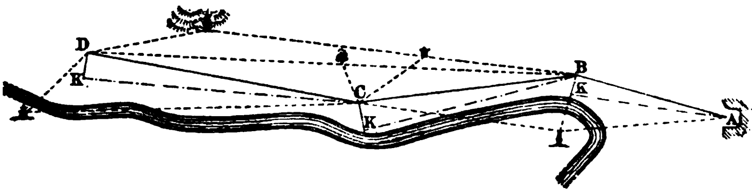
Soon after the Author had left on a visit to Europe in the spring of 1889, a serious accident occurred on the Taku-Tientsin section, by which five passengers, one English driver, and one

native fireman lost their lives. This was caused by the driver persisting in starting before the train coming from the opposite direction had arrived. There happened to be no second English official at hand to prevent him doing so. Even after this, the Chinese were very unwilling to admit their need of "foreign" help for the safe working of the trains.

SURVEYING.

There was difficulty in securing fairly good surveys without attracting attention by chaining, or any detailed work. Obviously, anything within three per cent. of accuracy was sufficient, and the following method sufficed. The instruments used were a small 3-inch theodolite, surmounted by a prismatic compass, fitted so that it could be easily detached. The former is used to measure the angle subtended between two flags, say B K in *Fig. 2*, which are placed by the leader of the party so that one is at exactly

Fig. 2.



right angles to the line of sight. This base is usually 100 feet in length, so that the cosine of the angle gives the distance. The base lines B K, C K, D K, are laid out by a wire rolled on a reel which forms a part of the ranging-pole. The other flag is on a tripod, with a box-square attached to its top, into which a rod is thrust. Four men without horses can do about 15 miles a day in open country, securing all landmarks and principal villages by cross bearings, as shown in *Fig. 2.* The same system has been used for river- and canal-work, the base being a lofty mast fixed in a boat, the angle being read by a sextant. The Author and Mr. Cox, in the winter of 1888-9, surveyed from near Peking to Tientsin in four days, and thus passed so rapidly over the ground that they were scarcely noticed. The party had several horses, which were, however, rarely employed.

The correctness of this system as regards length of traverse-lines was found by trial to be within $\frac{2}{1000}$ of accuracy; but the

permits, theodolite-readings can be taken in preference. The great advantage of this system is that, without exciting too much attention (sometimes a dangerous affair in China), many trial-lines can be run at small cost, and the route repeatedly shifted for any official caprice without the disappointment incidental to such a proceeding after a costly survey of the usual kind. To survey the numerous graves, which, at a glance, an engineer knows he cannot go near, would be wasted time and energy, and it is wiser, after a careful examination of the country, to at once try to drive a centre line in the correct direction, and after plotting this, to correct it as the obstructions may require. The Chinese, as a rule, invariably desire to have the railway as far from their towns, &c., as possible; but when the line is open, like people elsewhere, they lament that their demand was agreed to and acted upon. Unlike the Japanese, the Chinese students attached to the railway service have not as yet shown any aptitude for accurate surveying, but this is possibly due to the danger that they incur from the mobs which speedily collect, and the limited means provided for their protection in case of any disturbance.

European Staff and Climate.

One of the greatest difficulties in all introductions of western arts and manufacturing into the far East, is that of securing suitable Europeans or Americans to carry out the undertakings. Technical knowledge alone is insufficient to render a man capable of dealing efficiently with a people whose ideas are so entirely different from what he has been accustomed to previously. It is only those who combine a complete knowledge of their profession with a high sense of duty and tact, so that, while apparently giving way, they secure the desired result, who can really hope to do very much good. Not a little of the honour of introducing a better impression of foreigners to the Celestial mind is due to Mr. R. R. Burnett, M. Inst. C.E., who, however, was not spared to see the colliery at its prime, or the railway, which owes its existence to the success of the former. After much hard pioneer-work in Mongolia, Corea, and numerous parts of China, he left the Mining Company in 1882 to become the engineer and manager of a large undertaking on the Yangtze, but before work could be commenced he fell ill in Anhwei, and returned to Shanghai only to die. His agreeable manners and fine appearance, quite apart from his large and varied engineering ability, made him a great favourite with

all who really knew him, and in a remarkable degree smoothed the way to the introduction of European skill into China.

The climate of Northern China has changed during the last twelve years, and malaria has been very prevalent since the great floods of 1887, the summers of 1888 and 1889 being extremely unhealthy, and the death-rate amongst the Chinese unusually high. The most serious complaints are those prevalent all over China, namely, typhoid fever, dysentery, and a form of cholera; only one mild case of small-pox is to be noted, although it is very common amongst the natives during the winter months, but there is considerable discomfort from the sudden changes of temperature during the spring and autumn. Though the temperature in the province of Chili ranges from below zero to 105° in the shade, the cold is not so trying as that of England, owing to the extraordinary dryness of the winter months. The rains begin in July, and for two months are almost continuous, the country soon being flooded to a serious extent. It will thus be seen that engineering works can only be carried on for a short period of each year, except under serious difficulties. In 1888–89 a considerable amount of masonry was erected during the coldest weather by using 8 per cent. of sea salt mixed with the water employed for the cement mortar, and the results appear excellent, but the short hours worked by the men, and the difficulty of handling tools, except under a bright sunshine, renders all winter work out of doors unusually expensive. Luxury of any kind is practically unknown outside of the foreign settlements along the coast, and the railway man of the future must expect to be isolated from his fellows in situations where nothing but an intense love of his work and of nature can make life endurable.

In the Appendix will be found a complete list of the officers employed on the railway staff, which, owing to the loss of the Tung Chow extension, has been reduced to three engineers, a locomotive superintendent, and a traffic manager, under whom are nine foreign foremen, guards and drivers. The Mining Company employ, in addition, fourteen foreigners for various purposes in connection with their collieries, shipping, and cement works.

Railway Outlook in China.

The first train reached Tientsin in August, 1888, and in the following month the Viceroy went over the whole line with a large staff of officials, returning the next day, after spending several hours at the Tong colliery, with which he was greatly

paralysis which followed, possibly owing to exposure on the car-platform during the greater part of the journey, His Excellency lost no time in attempting to push the line on to Tung Chow *en route* for Peking. This scheme was shortly afterwards agreed to, and duly sanctioned by Imperial edict, but, when all was ready for a start, the sanction was withdrawn, and the whole affair stopped. The opposition was undoubtedly from those officials in Peking who profit by the tribute rice being conveyed by boat to Tung Chow, and thence by an extraordinary canal system to the capital. The suggested line had already been shifted away from the river towns, and everything was done to satisfy the grave owners and opposition boat people, but this was insufficient to appease those in high authority, who would not permit any interference with their vested rights. The Throne then referred the matter to the Viceroys of Provinces, most of whom reported in favour of the scheme, having, of course, first dutifully ascertained that the Empress, the Seventh Prince, and H. E. Li Hung Chang were strongly supporting it. Things began to look a little promising, when the Viceroy of Canton reported strongly against any railway being permitted to approach Peking from the sea coast, and afterwards, to prove he was not afraid of railways, however much he detested foreign ideas, advocated the celebrated so-called Great Western Railway from Hankow to an unimportant town 7 miles south-west of Peking, keeping as far away from the coast as the nature of the country would permit. Much to His Excellency's astonishment, the scheme was at once agreed to, and he was requested to immediately raise funds and start the work, carrying out his own policy of utilizing none but Chinese capital. This was naturally found to be impossible, and to put off the evil day the Government were induced to give instructions that all rails and rolling-stock should in addition be made in China.

There is naturally in China a desire to construct their railways out of their own materials, and if for technical reasons this idea may be erroneous, it is one which all can heartily sympathise with. It must always be remembered that in China, more than elsewhere, the Government hold their position solely by the good will of the people, and the numerous powerful guilds, should their interests be in any way assailed, are quite able and willing to defend their rights. Whatever good railways can effect in the immediate future, they must, in one form or another, for a certain period, seriously interfere with a vast number of workers, who cannot be assured that the change will bring any adequate improvement to

those who live from hand to mouth, and cannot wait for results. And such form the bulk of the Chinese population, and they can at any moment be roused by interested persons to block the path of progress. For this reason changes must be gradual, and the hardships brought about must be confined to small sections where they can be effectively remedied, and where any outcry will be too small to attract serious attention. The improvement of trade and introduction of various manufactures along the line of railway will soon create new demands for labour, and the slow extension of the various branches can be then undertaken without any fear of local opposition. Under such conditions railways cannot be so economically made as in Europe; but if laid out with due care and the isolated portions eventually connected, the results would in the end be perfectly satisfactory. Unfortunately this is difficult to accomplish in a country where each province has a separate Viceroy, and every Viceroy different ideas as to what is necessary.

In many districts, and especially near large towns, the graves will form an insurmountable barrier, and in Tientsin the station yard was placed in a swamp, which required raising several feet, in order to secure a suitable site. Many graves, probably over three thousand, have been removed without very serious trouble, but these have been exclusively those of the poorer classes, who are less superstitious than their superiors, and possibly more easily influenced by money. In many places the line was deflected several hundred yards to avoid graves of parents of officials, and it is entirely out of the question to bring it anywhere near these. It is for this reason that, in spite of the excellent configuration of the land, sharp curves will be numerous in places where the population is massed. In the extreme southern provinces the dead are buried amongst the hills, and the plains are entirely free from this class of obstruction; but, on the other hand, the land is very expensive (usually over £80 per acre for rice land), and the innumerable creeks necessitate a great amount of bridging. Added to this, the more determined and warlike character of the people, and their intense hatred of foreign introductions, renders the prospects of railways in Southern China far more gloomy than in the North.

At present China possesses rather under 100 miles of standard gauge main line, and some 20 miles of 3-foot 6-inch gauge on the Island of Formosa. The capital so far expended on the former amounts to 1,200,000 Taels, equal to £280,000 exclusive of wharfs and real estate not used for railway purposes, or almost exactly

£2,800 per mile of main line. This extremely low figure was due in a great measure to the skilful management of the Company's affairs by their agent in London, Mr. James Whittall, who took full advantage of the low prices ruling during 1888, and whose arrangements for shipping enabled the goods to be landed under peculiarly advantageous conditions.

The Paper is accompanied by various drawings, from which the *Figs.* in the text have been prepared.

[APPENDIX.

APPENDIX.

ENGINEERING STAFF EMPLOYED IN THE CONSTRUCTION OF THE RAILWAY FROM LUTAI to TIENTSIN, and from TONGSAN to LINSI.

A. W. H. BELLINGHAM, Assoc.M.Inst.C.E.[1]	Resident Engineer, Tientsin.
W. WATSON, B.E., Dublin[1]	" " Tongku.
ALEX. COX[1]	Assistant Engineer.
T. W. T. TUCKEY, B.E., Cork[1]	" "
D. P. RICKETTS, Assoc.M.Inst.C.E.[1]	" "
A. J. ARCH, Assoc.M.Inst.C.E.[2]	" "
A. S. VOWELL[2]	" "

[1] These received a gold medal from H.E. Li Hung Chang in commemoration of the opening of the railway to Tientsin.

[2] These left the service prior to the completion of the railway.

ROLLING STOCK.

No.	Description.	Capacity.	Weight.	Wheels. Nature.	Wheels. Diameter.	Journals.	Frames.	System.
			Tons.		Inches.	Inch. Inch.		
1	State car . . .	50 persons .	20	W. I. disc . .	42	8 × 3½	Steel . .	Cleminson's (8-wheel).
6	Composites . .	26, 1st class . / 48, 2nd class	19	„ . .	42	8 × 3½	„ . .	3 Cleminson's (8-wheel). 3-bogie.
12	2nd class . . .	100 passengers	19	„ . .	42	8 × 3½	Steel . .	3-Cleminson.
..	..	..	..	..	..	..	Teak . .	3-bogie.
160	Coal wagons . .	10 tons . .	5	W. I. spoke .	42	8 × 3½	Iron . .	4-wheel.
32	Stone cars . .	16 „ . .	7·5	C. I. chilled .	33	7 × 3½	Oregon .	Bogie.
90	..	..	..	W. I. spoke .	33	7 × 3½	..	„
25	Goods cars . .	20 tons . .	10	C. I. chilled .	36	7 × 3¾	Oregon .	U.S. Bogie.
25	„ . .	20 „ . .	12	W. I. spoke .	42	8 × 3½	„ .	Standard bogie.
6	Brake vans . .	..	5½	„ .	42	8 × 3½	Iron . .	4-wheel.
60	Construction . .	6 tons . .	3	Cast steel . .	30	6 × 3	„ . .	„

Steel and disk wheels of Krupp's make; wrought-iron, English hydraulic-forged; chilled cast-iron from the United States.

(*Paper No. 2476.*)

"The Gas-Supply of Buenos Ayres."

By George Ernest Stevenson, M. Inst. C.E.

There are no less than five gas-companies in Buenos Ayres, each possessing the privilege of supplying gas to private consumers throughout the municipal limits. The central portions of the city form a battle-ground in which three of these companies have for nearly twenty years contested the field, thus giving rise to an unnecessary capital expenditure and to increased cost in the production of the gas. The information that can be obtained as to the early history of gas-lighting in Buenos Ayres is of a very indefinite nature. Owing to the absence of proper records little can be known of the cost of manufacture, of the consumption of gas in proportion to the population, or of the relation existing between capital expenditure and the manufacturing capacity of the gas-works.

History of the Gas Companies.

The Primitive Gas-Company.—The first public exhibition of gas-lighting in Buenos Ayres was made by a certain Mr. Eugene Picard, who as an experiment illuminated the statue of Liberty in the "Plaza Victoria" with gas made on his own premises, on the occasion of the festival of the commemoration of independence on May 25th, 1854. The first concession for gas-lighting was given within the year as the result of this experiment. This concession conferred a monopoly of public lighting for twenty years, the municipality contracting to light 400 public lamps at the price of 110 dollars of the then paper currency (16*s.* 6*d.*) per lamp per month. The area embraced by this contract was equal to about two square miles. The public lamps were to give a light of 18 candles, but no method of testing the gas was prescribed. The concession gave also a monopoly of the sale and fixing of gas-fittings and of every appliance relative to the use of gas. A company, partly English and partly native, with a capital of £60,000, was formed to carry out the concession, and denominated

x 2

Company"). The works, which were capable of manufacturing from 60,000 to 70,000 cubic feet of gas per diem, were situated on a square of land (about two acres in extent) fronting the River Plate at the north end of the city. The supply of gas was commenced in 1856, and for the first five years no dividends were paid, nor were any accounts published. In 1861, however, the directorate gave a bonus to the shareholders of two shares for every share held, thus trebling the nominal capital, and then paid a dividend of 22½ per cent. on the augmented capital of the company. It has now become a purely local company, the name being changed to the "Compañia Primitiva de Alumbrado á Gas." It is governed by a local directorate, and the works are managed by a French engineer.

The Argentine Gas-Company.—The next gas company to appear in the field was that now known as the "Compañia Gas Argentino." In the year 1869 a French resident of the city proposed the manufacture of gas from animal fat as being a cheaper source of production than European coal. The proposition was well received, the municipality gave a fresh concession for this new kind of gas, and a company was formed to carry out the project. Mr. George Bower of St. Neots, Hunts, contracted for the construction of these gas-works, and in August, 1870, the new company began to supply oil-gas of 40 to 45 candle-power. The works were situated at the west end of the city, about two miles from the river side. The burners used with this gas burnt 1½ cubic foot per hour, and yielded a light of about fourteen candles. After two years' working it was perceived that the use of animal oil was too costly, and the works were converted for the distillation of coal. At that time three beds of retorts were found sufficient for the requirements of the company.

The Buenos Ayres (New) Gas-Company.—In the year 1871, owing to the dissatisfaction felt by a number of the consumers of the Buenos Ayres Gas-Company, the formation of a third company was proposed by a German gentleman named Jaeger, and a concession having been obtained, it was formally constituted in March, 1872. An offer was made to take over the public lighting on the expiration of the contract with the Compañia Gas Buenos Aires, and this proposal having been accepted by the municipality, a contract was signed on *October 11th*, 1872, to light 4,200 lamps for a period of ten years dating from 1874. It should be here explained that concessions for gas in the Argentine Republic usually give monopoly of public lighting,

but do not preclude competition in private consumption. The newly-formed company took the title of "Sociedad Anonima Consumidores de Gas." The capital was 1,000,000 gold dollars, or £200,000 sterling. The site chosen consisted of two squares of land situated in the suburb of Barracas at the south end of the city; the works were designed for a daily make of half a million cubic feet of gas, and were a great advance upon previous undertakings of the kind in Buenos Ayres. The supply-main from the works to the city was 18 inches in diameter for a short distance, and was then reduced to 15 inches, with a branch main 10 inches in diameter passing through another part of the town. The rest of the main-piping was of small dimensions, a large proportion consisting of 2-inch pipes. The Company's mains covered the whole of the centre of the city from Calle Brazil in the south to Calle Santa Fé in the north. Subsequently a portion of the suburb known as the "Boca" was also supplied with gas by this company. Considerable difficulties were experienced during the first few years of working, and towards the close of 1876 the undertaking was transferred to a London company, and the name changed to "The Buenos Ayres (New) Gas-Company, Limited."

The Belgrano Gas-Company.—In the year 1874 a gas-company was formed to light the then provincial town of Belgrano, situated six miles to the north of Buenos Ayres. This company also obtained powers to supply gas within the municipality of the capital. The works, which are situated in Belgrano, were originally planned for a make of 60,000 cubic feet per diem.

There were thus four companies supplying gas within the limits of the municipality of Buenos Ayres, and now, Belgrano having been incorporated within those limits, all four gas-works are actually situated in the municipality. The Belgrano works also supply Flores, a suburb to the west of the city, and recently included within its boundaries.

During the ten years following the rise and establishment of these new gas-companies the political affairs of the Argentine Republic were in an unsatisfactory state, and the city of Buenos Ayres suffered a period of stagnation in consequence. After the revolution of 1880 the political atmosphere cleared and a re-action took place; new houses were built and new streets opened. In January, 1885, the Author was appointed engineer to the Buenos Ayres (New) Gas Company, and soon found that the growing requirements of the city demanded an increase in the manu-

foreseen the rapid increase of the population.

In the winter of 1885 the daily make of gas at the four gas-works supplying Buenos Ayres was approximately as follows:—

	Cubic feet.
Primitive Gas Company	400,000
Argentine Gas Company	250,000
Buenos Ayres (New) Company	600,000
Belgrano Gas Company	150,000
Total	1,400,000

As the consumption in summer is about two-thirds of what it is in winter, the average total daily make was about 1,100,000 throughout the year, or say a total annual make of gas of 400,000,000 cubic feet. Of this quantity of gas at least 25 per cent. was unaccounted for.

The large extent of main-piping in proportion to the consumption of gas, and the fact that each of the companies had numbers of service-pipes lying in the ground, unutilized and neglected, but in communication with the mains, all combined to bring about a high percentage of loss. In addition to this the construction of the drainage works carried out by Mr. Bateman for the Government, which had been re-commenced with vigour a few years before, had caused a disturbance of the soil in the streets of the city, and produced a disastrous effect upon the numerous decayed service-pipes and badly-jointed mains. The Buenos Ayres (New) Gas Company lost 26 per cent. of all the gas manufactured in the year 1885. The leakage of the Primitive Gas Company in that year was said to amount to 30 per cent., and that of the Argentine Gas Company was 16 to 18 per cent. Taking it all round at 25 per cent. the consumption of gas may be put down at 300,000,000 cubic feet, the population of Buenos Ayres being at that time 400,000. The gas consumed per head of population per annum was therefore 750 cubic feet.

The number of public lamps then lighted did not exceed three thousand two hundred and fifty, for although the contract for public lighting specified four thousand two hundred lamps, the numbers had in previous years been reduced by arrangement with the municipality, owing to inability on the part of the latter to pay for the extent of lighting contracted for.

Improvements of the Buenos Ayres (New) Gas-Company.

The first step towards improving the supply of gas was taken by the Buenos Ayres (New) Gas Company in the year 1885. Their contract for public lighting having expired in October, 1884, a new contract for ten years was entered into in which the company undertook to extend the lighting over a much larger area, as and when the streets requiring to be lighted should be paved. The Company then turned its attention to reforming the system of main-piping. At the further extremities of the district the pressure in the mains during the hours of heaviest consumption did not exceed 3½-tenths of an inch, even when 30-tenths were given at the works. A plan for the re-construction of the main-piping was prepared by the Author, and with some modification was accepted by the Directorate. The district supplied embraced an area of about 8 square miles, forming a parallelogram 4 miles long and 2 miles wide. Inasmuch, however, as it would become necessary after extending the supply of gas to add to the storage capacity, and having regard to the unsuitable nature of the ground at the works for erecting gasholders, the Directors, by the advice of their consulting engineer, Mr. S. Simmelkjör, decided to lay a pumping-main to deliver the gas to a gasholder at the farther end of the city, from which it should be conducted by a leading distributing-main into the general system of mains at various points.

The principle of distribution proposed by the Author was that of dividing the city into a certain number of sections of more or less equal area, each of which should be surrounded by mains of large diameter. These mains, which were to receive their supply from three principal leading-mains, ran parallel with each other and equidistant. The arrangement of the streets in Buenos Ayres is peculiarly favourable to the adoption of such a system. The city is laid out on the Spanish plan of "cuadras," or squares, all the streets being parallel and at right angles one with another, the distance from one cross corner to another being 150 Spanish yards. By the Author's suggestion a distributing-main 18 inches in diameter was laid in the boulevard, "Entre-Rios-Callao," receiving its supply from two governors at the ends of the line. The pumping-main was laid parallel to it in the next street to the west of the boulevard, and at the south end of the line the exhausting machinery was fixed together with the first of the two governors. By this means the necessity of pumping through the

whole length of the main from the works was avoided, and the portion of the main under pressure was reduced to about half the entire length. The site chosen for the new gasholder station was in the north-west part of the town, a neighbourhood at that time very little populated, but which has since greatly developed. A gasholder capable of containing 600,000 cubic feet of gas was erected, leaving space for another holder of equal dimensions.

Seven sectional cross-mains were laid at equal distances connecting the two 18-inch mains at the east and west and the 10-inch main running midway between them, with each other. These mains were of 12, 10 and 8 inches diameter. To them were connected all the secondary mains running north and south, so as to form fourteen rectangular parallelograms, each constituting a section embraced by large supply-mains, and comprising the whole of the central and densely populated part of the city. All the mains within each section were connected together by right-angled crosses at the junctions of the streets.

Inasmuch as it was anticipated that when sufficient pressure was obtained throughout the district, a very rapid increase in the consumption would be experienced, and as the works of the company were already too small for the make of gas, the Author presented a plan for the extension, and ultimate re-construction of the works. This plan was never carried out, although the extra land required for its realization was purchased. Certain improvements were, however, undertaken, the retort-settings being entirely re-constructed on the regenerator principle. These and other improvements occupied a period of two years. After their completion and when the new gasholder was put to work, the consumption of gas increased greatly, and in the winter of 1888 the daily make rose to 1,000,000 cubic feet, which was produced in the original retort-house, designed for a make of half that quantity only. The loss by leakage from the mains and service-pipes was brought down to 12 per cent., instead of 26 per cent. as before.

Improvements of the Argentine Gas-Company.

The Argentine Gas-Company has entirely reconstructed its works, the site of which was very limited in area, so that in order to meet the demands of their increased consumption, it was necessary to utilize every part of the land to the utmost extent. At present the Argentine Gas-works can manufacture 600,000 cubic feet per diem and store 300,000 feet; but the company is now erecting a new holder on an adjoining piece of land which

will make the storage capacity equal to that of manufacture. The consumption of the gas supplied by this company has doubled in five years.

Improvements of the Primitive Gas-Company.

The Primitive Gas-Company awoke from its lethargic condition in the year 1887. The services of a French engineer named Lerou were secured, and he made an elaborate report on the condition of the works, and on the improvements and extensions which he proposed to carry out. In the winter of 1888 the Primitive Gas-Company were manufacturing from 700,000 to 750,000 cubic feet of gas per diem, and to accomplish this their plant was strained to its utmost capacity. By the time the following winter arrived, part of their retort settings had been re-constructed on the generator system of Mr. Liegel. Besides the reconstruction of the retort-settings, this company undertook the erection of a new gasholder, designed by their engineer, and situated at some distance from the works, near "Palermo" park. This is to be 40 metres (131 feet 3 inches) in diameter, and it will be provided with the external jointed connecting-pipes, which are much used in French gas-works. At the present time the tank, which is of brick rendered with cement, is in course of construction.

Improvements of the Belgrano Gas-Company.

The Belgrano Gas-Company has also during the last five years largely extended its business, and increased the size of its works. At the present moment these works are capable of manufacturing 350,000 cubic feet of gas per diem, and their engineer, Mr. Quirk, intends to double their capacity.

Annual Make and Consumption of Gas at the Present Time.

At the close of the year 1889, the average daily make of gas in the four gas-works was roughly as follows :—

	Cubic feet.
Primitive Gas Company	800,000
Argentine Gas Company	500,000
Buenos Ayres (New) Gas Company	1,000,000
Belgrano Gas Company	300,000
Total	2,600,000

This average daily make is equal to 950 millions per annum. Of this quantity 15 per cent. may be considered as lost by leakage, and otherwise unaccounted for, leaving about 800 millions as the net amount of gas consumed during 1889.

The population of the city of Buenos Ayres has increased by about 100,000 during the five years ending with 1889, and is now estimated at 500,000 inhabitants, so that the average consumption per head of population is now 1,600 cubic feet, or more than double that of five years ago. This increase is a remarkable evidence of the growing prosperity of the city of Buenos Ayres, and also of its adoption of the customs and habits of European cities. Formerly the inhabitants were afraid to introduce gas into private residences, the use of it being chiefly confined to houses of business and public offices. Now nearly every house is fitted with gas-piping when built, and tenants expect to find gas laid on when they occupy a house.

Regulations of Supply and Quality of Gas.

At the close of the year 1884, when the first ten years' contract between the Buenos Ayres (New) Gas Company and the Municipality expired, and negotiations were entered into for its renewal. Mr. Thomas E. Quirk was appointed Municipal Inspector of Public Lighting, and to him the contract was submitted for revision in respect of the conditions of lighting, and the regulations as to the quality and pressure of the gas supplied.

Mr. Quirk, in conjunction with the Author, whose advice was requested, represented to the Municipal authorities the desirability of introducing into the contract proper conditions for testing the quality and illuminating power of the gas in the manner usual in European cities.

It was eventually agreed that the gas supplied by the contracting company should possess an illuminating power of twenty candles as tested against sperm candles with the Sugg London Argand, or the bats-wing burner, if over twenty candles, and the conditions prescribed by the London Gas Referees for testing were incorporated in the contract. It was determined that the lamps should be supplied with burners consuming not less than 4½ cubic feet per hour, the company being left free to choose the class of burner to be employed.

The contract also stipulated that the gas should be free from sulphuretted hydrogen, and that it should be delivered at the burners with a minimum pressure of $\frac{8}{10}$ths inch. The price

for the public lighting was fixed at 4 dollars 15 cents of the new national currency per lamp per month, the company doing all the lighting, cleaning, and repairs, but the Municipality providing all lamps, brackets, and columns.

Since the date of the new contract, the gas supplied by all the companies has from time to time been tested by the Municipal Inspector as to its pressure, purity, and illuminating power, and a decree has been passed enforcing the testing and stamping of all gas-meters. The regulations for meter-testing are of a stringent character, no greater margin being allowed than 1 per cent. fast, and 2 per cent. slow. A tax of 4 dollars on every meter stamped, which was for some time charged to the consumers when the meters were fixed, is now paid by the companies out of their own pockets. The imposition of this tax exercises a prejudicial effect, inasmuch as the companies are reluctant to remove a meter for examination and repair, as the tax must be paid again each time it is refixed.

Price Charged for Gas and Cost of Manufacture.

The price charged by the different gas-companies to private consumers has not been changed during the last five years, but the actual value has become much reduced by reason of the depreciation in the paper currency.

In January 1885 the Argentine Government decreed the forced currency of the paper dollar, which up to that time had been equal to gold value, the rate of exchange with British money being 5·04 dollars to the pound.

The nominal price charged by the Primitive Gas Company was 5 dollars 80 cents, and by the other companies 5 dollars 20 cents per 1000 cubic feet. The latter was equal at gold value to 20*s.* 8*d.* of English money, but at the close of 1889 it was worth in paper just half this amount, gold having risen to a premium of 100 per cent. The gas-companies in consequence have agreed to raise their price 25 per cent.

The first consideration that will strike an English gas engineer is that the price charged must be out of all proportion to the cost of making the gas. Expenses, however, differ greatly. In the first place, the cost of the coal is quite a different item from what it is at home. The constant habituation in such a climate to a brilliant sunlight by day makes it imperative that the artificial light used at night should be of more than ordinary brilliancy.

power, as they find that nothing less will satisfy the consumers, and in order to produce this quality of gas 40 per cent. of high-class cannel is used, or, as in the practice of the Primitive Gas Company, only Wigan cannel of second quality is carbonized.

During the years 1885, 1886, and 1887 the average cost of coal and cannel in the proportions used was $12\frac{1}{2}$ gold dollars or £2 10*s.* per ton. At the present moment it is considerably higher, as not only have the prices risen, but freights have increased greatly. A ton of Newcastle coal costs to-day 12*s.* per ton F.O.B. plus 35*s.* for freight and 3*s.* for unloading and transport to works; say altogether 50*s.* The cannel required for the gas-supply of Buenos Ayres costs 40*s.* per ton F.O.B. and 38*s.* expenses, equal to 78*s.* per ton on the works, so that a mixture of 40 per cent. cannel and 60 per cent. coal costs 61*s.* per ton, or say 6*s.* per 1000 cubic feet of gas manufactured. Owing to the depreciation of the paper money, wages, although nominally higher, are in reality less than formerly, and carbonizing costs now 8*d.* per 1000 cubic feet as against 1*s.* formerly. This is also partly due to the introduction by the Author of the regenerator system of retort-heating, inasmuch as the retorts now carbonize a larger quantity of coal in a given time than formerly, and fewer stokers are required. Adding to these expenses 10*d.* as the cost of salaries of officials and repairs of works, the total cost of manufacturing gas amounts to 7*s.* 6*d.* per 1000 cubic feet. Five years ago the manufacturing expenses amounted to 10*s.* per 1000 feet, of which sum the coal absorbed 5*s.* only.

The expenses of distribution in Buenos Ayres are also very high. In consequence of the competition between the three companies, the amount of work done in fixing and disconnecting meters, laying and cutting off service-pipes, is three times as great as would be necessary to obtain the same increase of consumption if each company possessed a field of supply in which it had a monopoly. During one year of the Author's management the Buenos Ayres (New) Gas Company fixed 1,500 meters, but the net increase did not exceed 600, because 900 consumers had seceded and taken a supply of gas from one of the other companies. Had the company simply been required to take on the six hundred consumers that constituted the net increase of the year, the work would have employed less than half the number of gas-fitters actually engaged, and the staff of clerks would also have been much reduced. The cost of distribution averaged 1*s.* per

1000 cubic feet during the years 1885, 1886 and 1887, and the cost of management was about 1*s.* 6*d.* per 1000 feet, including rent of offices and municipal and other taxes. Allowing 15 per cent. for leakage and loss, the cost of manufacturing per 1000 feet consumed amounted to 8*s.* 10*d.*, and the total cost of supplying gas was as follows:—

	s.	*d.*	
Manufacture	8	10	
Distribution	1	0	
Management	1	6	
Total	11	4	per 1000 feet sold.

During the past three years (1886–1889) the premium on gold has risen to 100 per cent., so that the original price, which was equal to 20*s.* 8*d.*, has in effect been reduced to 10*s.* 4*d.*, but the companies have increased the price by 25 per cent., making its present value 12*s.* 11*d.* The profit, therefore, at the present time is about equal to 1*s.* 7*d.* per 1000 cubic feet of gas sold. This profit is only obtained from the private consumption.

The price for the public lighting is $4 15*c.* paper money per lamp per month. The lamps consume on the average 1,350 cubic feet of gas per month, giving a return of $3 75*c.* per 1000 cubic feet, or 7*s.* 6*d.* of English money. At the commencement of the year 1885 the number of public lamps lighted was 3,250; at the present time it is 7,000.

The Co-operative Gas-Company.

In the year 1887 a new concession was given by the Municipality to Mr. John Storni, for the purpose of providing a supply of gas in those outlying portions of the city to which the existing companies had not extended their main-piping. Owing to the rapid increase of the population and the previous defective condition of the works and mains of the different companies it had been impossible for them to keep pace with the extension. There remained, therefore, a large area in the west and south in which there was no gas-supply, and a still larger area over which it was partial and imperfect.

The concession given to Mr. Storni gave power to supply gas throughout the whole municipal limits, and as about the same time the municipal boundaries were extended, so as to include the suburban townships of Flores and Belgrano, there was a large new field open for the supply of gas. A company consisting

"Sociedad Co-operativa de Alumbrado á Gas." The statutes of this company provided that consumers who were shareholders should be entitled to a 10 per cent. reduction in the price of gas. After some delays the directors made a proposal to the Author to undertake the construction of their works, and his retirement from the management of the Buenos Ayres (New) Gas Company followed as a necessary preliminary to accepting this responsibility.

The site chosen is in the south-west part of the city, and is in communication with the port of the Riachuelo by a branch of the Provincial Railway. The area of the site is 5 acres. The works have been designed for an immediate daily make of 1,500,000 cubic feet. The most modern form of carbonizing plant has been introduced, and the condensing, scrubbing, and purifying apparatus are all of modern design and ample capacity. The storage capacity is 1,200,000 cubic feet, and there are two exit-mains from the works, one of 24 inches, and one of 18 inches, diameter. The main-piping extends over 180 kilometres of streets, and embraces the whole of the western and southern portions of the city, but leaves the centre untouched.

The works are at the present moment almost completed, and will shortly be put to work. The cost of the works has been £108,000, and of the mains £102,000.[1]

At the present time the number of houses in Buenos Ayres is about 40,000; the number supplied with gas may be taken at 25,000, divided amongst the different companies as follows:—

	Consumers.
Primitive Gas Company	9,000
Buenos Ayres (New) Company	8,000
Argentine Gas Company	5,000
Belgrano Gas Company	3,000
Total	25,000

[1] Since this Paper was written the Argentine Gas Company and the Co-operative Gas Company have amalgamated, it having been considered by the Directorate of the latter Company inexpedient to commence a competitive business in view of the financial and political crisis through which the Argentine Republic has passed during the last few months. A reduction in the cost of freights for coal has taken place, cargoes being now shipped (October 1890) at from 24*s*. to 26*s*. per ton, in place of 35*s*. at the time the Paper was written. The works of the Co-operative Gas Company are more fully described in the 'Journal of Gas Lighting,' Nov. 4, 1890, p. 955.—G. E. S.

There remain, therefore, 15,000 houses unsupplied with gas. It must not be supposed that these 15,000 houses are of too poor a character to take gas, for all of them are included in the system of drainage and water-supply carried out by the Government, and must bear the cost of the internal drains, a compulsory outlay, and of the heavy rates imposed for both drainage and water-supply. At the beginning of 1885 the number of houses supplied with gas was 16,000, or just half the total number then existing in the Municipality. To-day the number supplied with gas exceeds 60 per cent. of the total.

The more general use of electric light, or the introduction of "water-gas," or oil-gas, may possibly create a temporary disturbance, but up to the present time there has been no indication that any of these systems of lighting are likely to seriously affect the coal-gas industry. Electric light, both in the arc form and the glow-lamp, has for several years been employed in the illumination of Buenos Ayres; but there is no evidence that electric lighting is making headway as against gas, and the use of it does not appear to be permanently established even within the limited area which it occupies.

The Paper is accompanied by three plans. Plan No. I shows the position of the gas-works, and the area supplied by each company; Plan No. II shows the systems of piping carried out by the Author for the Buenos Ayres (New) Gas-Company; and Plan No. III shows the system and district occupied by the piping of the Co-operative Gas-Company.

(*Paper No. 2485.*)

"Conversion of Metre Gauge to Indian Standard (5 feet 6 inches) Gauge on the Bengal Nagpur Railway."

By George Moyle, M. Inst. C.E.

The Bengal Nagpur Railway is intended to connect Nagpur, the present terminus of the Great Indian Peninsula Railway, with Assensole on the main line of the East Indian Railway, 132 miles from Calcutta (Howrah), and to provide through connection without break of gauge between Bombay and Calcutta.

The total length of this route is made up as follows:—

	Miles.
Bombay to Nagpur, G. I. P. Ry.	520
Nagpur to Assensole, B. N. Ry.	621¾
Assensole to Calcutta, E. I. Ry.	132
Total	1273¾

The distance *viâ* Jubbulpur and Allahabad being 1,400 miles, the saving effected is about 127 miles. At Bilaspur, 775 miles from Bombay and 498 from Calcutta, a branch line on the standard gauge 199 miles in length, is also being constructed by the Bengal Nagpur Railway Company to Katni, on the East Indian Railway, at which place 38 miles already had been completed and worked by the government before the formation of the company. The whole of this branch railway is single line. The government had also previously constructed and worked for several years a metre-gauge railway, known as the Nagpur-Chhatisgarh State Railway, extending from Nagpur to Rajnandgam 145½ miles on the Nagpur-Bilaspur section of the Bengal-Nagpur Railway. The conversion of the gauge of this 145½ miles of line forms the subject of the present Paper, which is intended to show the cost per mile of this operation, apart from any expenditure necessitated by thus making the railway a trunk line, instead of a branch. When the company took over the property on May 9th, 1887, the year was so far advanced that it was necessary to postpone all preliminary operations till after the rainy season. The work was

commenced in October 1887, and the actual closing of the metre-gauge line took place on November 27th, 1888, the standard gauge having been completed ready for opening by the 15th October.

Land.—Additional land was required for the alterations described under earthwork, and for quarries for building materials and ballast.

Earthwork.—This work comprised the widening of all cuttings and embankments, and making new ones where the existing curves were too sharp for the wider gauge, constructing diversions at bridges, and extending the old station yards. The deviations were as follows:—

			Feet.
No. 1	chain	5650 to 5678	2,800
No. 2	„	5715·60 to 5778·60	6,300
No. 3	„	6158·40 to 6192·00	3,360

The total amount of work done was:—

	Cubic Feet.
Embankments	31,271,687
Cuttings	6,644,727
Total	37,916,414

or 1,404,312 cubic yards.

The only tunnel, 735 feet long, in very hard rock and unlined, was fortunately taken out originally to a section sufficient for the standard gauge, so that it required no alteration. It may be remarked here that, with one or two unimportant exceptions, no change was made in rail levels.

Bridgework.—1st. All girders above 3 feet in span, had to be replaced by stronger ones, necessitating corresponding masonry alterations.

2nd. All bridges, both girder and arch, required to have their wing-walls, face-walls or parapets, altered or raised, in consequence of the embankments being widened.

3rd. New bridges were required in deviations. But apart from these necessary changes, a far greater quantity of work had to be done in consequence of the unsatisfactory condition of many of the abutments and wing-walls, which were cracked and shaken through badly designed foundations, insufficient or complete absence of backing, inferior materials and bad workmanship. Advantage was taken of the opportunity afforded by the line being in a state of reconstruction to make additional waterway where experience had proved it to be required. Full details of bridgework executed are given in the Appendix.

girder-bridges was unimportant, and gave no trouble; the same may be said of masonry alterations to girder-bridges under 40 feet span, with the exception that in consequence of the new girders, rails, and sleepers being deeper than those displaced, and the rail levels remaining unaltered, it was necessary to lower the bearings of the girders. In order to do this the metre-gauge girders and line were slewed from side to side and notches cut in the masonry. These were temporarily filled by wood packings till the new girders and their timber bearing-blocks were substituted for the old ones.

The building of new bridges and altering old ones of spans above 20 feet was a source of difficulty only in so far as the time available was limited. Most of the new bridges were founded in what is known locally as black cotton soil, and required concrete 6 to 8 feet deep under the footing courses.

The following abstract shows the quantities of materials used:—

Material.	Quantity Delivered by Train.	
	Cubic Feet.	Tons.
Ballast for concrete	228,143	10,379
Stone for coursed rubble-masonry	295,544	22,675
Stone for ashlar-masonry	44,581	
Rubble for backing	177,173	7,119
Lime	64 828	2,312
Ironwork in girders	..	2,945
Totals	810,269	45,430

The following plan was adopted in dealing with bridges under 40 feet span. The new girder-spans were riveted together complete at the depôts, and the cross-sleepers fixed, levelled, and notched ready to receive the rails on the mixed gauge. A train of wagons was then loaded with them, and sent out together with a 10-ton travelling crane; on arriving at a station the crane and one or more spans, according to the time available, were taken by the engine to bridges outside the station, the line uncoupled and the rails pulled up, the old span removed by the crane and placed to one side, the notches in the masonry dressed true, the timber bearing-blocks fitted to them, the new span placed complete on the bridge by the crane, the old one picked up and put on the empty wagon, and the rails relaid over the new girders. As many as seven bridges have been thus completed

in a single working day, but the number depended on the amount of traffic at the time, the average being four. In those cases where the line was carried during the alteration by a diversion and temporary bridge, the new girders were of course erected, and the permanent way on the mixed gauge fixed, without any special arrangements being necessary. For spans above 20 feet and under 150 feet, derricks were generally used, but where the circumstances were favourable the plan of rolling the old girders off and the new ones on, either end-ways or side-ways, was adopted. In all cases the sections of the main-girders were riveted together off the bridge. The actual cost of erecting and painting the iron-work for spans up to 60 feet, including the removal of the old material and freight to and from depôts, calculated on the weight of new work only, was as follows:—

Spans under 40 feet	Rs. 22 per ton.
Spans of 40 feet and 60 feet .	„ 35 „

Weingunga Bridge.—The alteration of this bridge (nine spans of 150 feet), which was done subsequently to the line being opened to traffic on the standard gauge, was effected by supporting the new girders on the old ones till the former were riveted up, and then lowering the latter in sections from the former. The new main girders were erected and riveted up between, and on the flooring of, the old girders. Travellers running on the top-booms of the old girders were used in erecting the new ones, the sections of which were conveyed in lorries on the old metre-gauge line, supported on the flooring, which was just above the bottom booms. Each pair of new main-girders when riveted up was supported on the piers by stacks of packings, and the wedges were struck. The new girders—which had to be spaced in the first instance so as to leave a clear way for trollies, and also room for riveters to work between them and the old girders—were then traversed sideways as far as possible towards the old girders, sufficient room being left to enable rivet-cutters to work on the latter. Temporary cross-bracings were next bolted to the new girders which were raised on their packings so that their top-booms were about 5 feet above those of the old ones. Cross-beams were then laid across the top-booms of the new main girders, one on either side of each of the four pairs of top main joints of the old girders which it was intended to cut, and the latter were slung from these cross-beams by chains and screw-couplings. When this was effected, the flooring and top cross-bracing having been meanwhile removed, the cutting of the eight supported joints

and of corresponding joints in the bottom-booms was completed. Each of the old girders was thus divided into five sections. Whilst this was in progress two pairs of cross-beams were fixed over the top-booms of the new girders, so as to project over the two centre sections of the old girders, and four treble tackles of 6-inch manilla rope were slung from the ends of the pairs of cross-beams, and made fast to the top-booms of the two centre sections of the old girders. As soon as the necessary rivets were cut, the chain lashings and screw-couplings were removed, and the two sections of girder were simultaneously lowered to the bed of the river 50 feet below, by paying off the ropes from smooth round spars. The remaining eight sections of each pair of old girders were sent down in the same way, except that two tackles instead of four were used. They were then cut to pieces in the bed of the river, sorted, and trained to the nearest station.

The girders of each span, as soon as all the old ironwork was out of the way, were lowered to within a few inches of their final position, and then traversed sideways, one at a time till they were in position, the one in motion being always stayed from the other. The cross-girders were then fixed, temporary bracings removed, saddle-gear put in place and the girders lowered on to it. Finally the rail-girders, flooring, timber-work and permanent way were fixed. The new saddles rested on the same surfaces as the old ones, and the rail-level was in consequence raised about 14 inches. The operation was commenced on the day the metre-gauge line was closed to traffic, November 27th, 1888, and the first train passed over the new girders on April 29th, 1889; but the work was not hurried, and could have been done in two-thirds of the time had it been necessary. The weight of ironwork dismantled was 879 tons, and of that erected, 1,230 tons, or in all, 2,109 tons.

The total cost of removing the old, and erecting and painting the new girders, including freight charges to and from depôt, but excluding all expenditure on the diversion and temporary bridge, was Rs.30,012 or £2,309; being at the rate of £1·88 per ton on the total weight of new ironwork only. Calculated on the total weight of both old and new, the amount per ton was Rs.14·23 or £1·09. The cost of the diversion and temporary bridge was Rs.22,973.

Ballast.—It was necessary to provide an additional quantity of 9,778,219 cubic feet of stone ballast, which was obtained without difficulty. The cost per mile of track was about Rs.2,513 or £193 6*s.* 2*d.*

Permanent Way, including Points and Crossings.—The metre-

gauge line was laid throughout with flat-footed rails, weighing 40 lbs. per yard, on wooden cross-sleepers, 6 feet long: the new standard gauge permanent way consisted of steel flat-footed rails weighing 75 lbs. per yard, on steel sleepers of the inverted trough pattern, with lugs punched out of them under which the foot of each rail was held by steel keys tapered and split. These sleepers, which weighed about 120 lbs. each, were, for the purposes of conversion, manufactured with four pairs of lugs each, the outside pairs to hold the 75-lb. and the inside pairs to hold the 40-lb. rails. A mixed-gauge line consisting of four rails was thus easily laid; but, in consequence of the steel sleepers being spaced a yard apart throughout to suit the standard gauge, the metre-gauge line, which required to be supported at intervals of 2 feet at the joints and 2 feet 9 inches apart elsewhere, could not be maintained in the best order for the running of metre-gauge trains. At the rail joints of the metre-gauge line, which were not evenly supported between the steel sleepers in consequence of the 40-lb. rails being 24 feet long while the 75-lb. rails were 30 feet long, it was found necessary to lay some of the old wooden sleepers.

Wherever diversions were necessary to bridge operations, the wooden sleepers which had been removed from the old line, and the 75-lb. rails temporarily idle in the mixed line were made use of. There were altogether sixty-two diversions of a total length of nearly 18 miles, all the more important of which were opened by the middle of February, 1888. It is satisfactory to be able to state that, although as many as twelve and fourteen trains passed over the line in a day, no accidents, and only a few detentions were due to plate-laying operations.

The new permanent-way materials were distributed along the line by metre-gauge trains, so that everything was ready to hand for carrying out the operation of laying described below. The inspector in charge at a "rail-head," who was kept advised of the running of trains by the nearest station-master, usually broke the line directly a train had passed; as much of the metre-gauge as it was considered possible to relay before the next one was likely to arrive was at once dismantled, the ballast having been previously opened out and roughly levelled, and spikes and fish-bolts loosened; metre-gauge rails unlinked at every fourth joint were merely pinched to either side so as to be clear of the new sleepers; whilst sleepers and small fastenings were thrown out clear of formation level. As fast as the metre-gauge material was removed, steel sleepers were laid down, spaced and lined true at the lugs by knotted cords. A gang of men followed, forcing the 75-lb. rails

rails were laid in the seats, and linked on, chalk marks were made along each rail to show the exact position of the sleepers, which were then adjusted by pinch-bars, and fixed by driving the steel keys under the lugs. Finally, the keys for the metre-gauge rails were driven in, and the line roughly lifted and packed ready for the next train.

There was a good reason for laying the 75-lb. or outside rails first. To get a rail to drop into its ten seats, all the sleepers had to be simultaneously held up by pinch-bars to one level, and to be at the same time in one line; and this was easily done with the 75-lb. or outside rails by the aid of a simple contrivance, made of round iron $\frac{5}{8}$ inch diameter, somewhat similar to the handle of an ordinary bucket, the ends of which clawed the sides of the sleeper, while the middle served as a fulcrum for the crowbar used to force the rail down. Once the 75-lb. rails were seated, there was no difficulty whatever in getting the 40-lb. rails into place, but the reverse was by no means the case.

The amount of laying which could be done in a working day, depended entirely on the running of trains, but the average progress was about half a mile. On two or three occasions one mile and a half was done in one day at one rail-head. Three hours was usually the longest period during which the line could remain broken. The cost of laying the mixed gauge, including removal of the old rails, but exclusive of carriage and distribution of material and finished topping of the line, was about $5\frac{1}{2}d.$ per yard; the cost, including all charges, was $1s.\ 0\frac{3}{4}d.$ per yard.

On bridges where new girder-work had to be fixed, the metre-gauge rails were left untouched pending the alteration, but the 75-lb. rails were in all cases linked over them, and subsequently removed, so as to avoid unnecessary cutting and short closures. In station yards—of which there were nineteen—the metre-gauge line and sidings were left alone and converted subsequently. When the mixed gauge had to be laid over new girder work special arrangements were necessary. At bridges under 40 feet in span, timber cross-sleepers were used and supported all four rails, but on other bridges longitudinal sleepers were employed, which afforded no support for the metre-gauge lines. Temporary longitudinals, 2 feet 6 inches apart, were therefore laid, consisting each of three 75-lb. rails nested, and across these short wooden sleepers were fixed to carry the metre-gauge line. In the approaches to all girder bridges, in consequence of the seats of

40-lb. rails on steel sleepers being below the level of the seats of 75-lb. rails, the metre-gauge line had to be supported for one or more rail-lengths, on wooden sleepers laid between the steel ones so as to gradually get all four rails to one level.

Points and Crossings.—In station-yards, after the existing sidings had been re-arranged as far as possible to suit the new conditions, they were converted to the mixed gauge, all metre-gauge points and crossings being left unaltered, with the exception that the wooden sleepers, which were 6 feet long, were replaced by others 10 feet long, to which all four rails could be fixed. The points and crossings for the standard gauge were then laid on wooden sleepers, so as to be out of the way of the metre-gauge points and crossings, and when this had been done, one or more rails were removed, so as to allow of the metre-gauge line being re-laid through. At all standard-gauge points, the metre-gauge line had to be carried on separate wooden sleepers, as explained in the case of girder-bridge approaches, so as to admit of its being raised sufficiently for cow-catchers of the engines running on it to clear the 75-lb. rails, which, being elevated on slide chairs, would otherwise have fouled them. The arrangements at the stations were therefore such that standard-gauge trains could be run as well as metre-gauge trains.

Several trial trains were run on the wider gauge, and on the day the line was opened to traffic the down trains, out of Nagpur, ran on the standard gauge, and the up trains on the metre gauge. The crossing of these trains at stations was managed without the slightest inconvenience or delay, it being only necessary to temporarily remove and re-lay a few rails when it was required to run on the standard gauge over a line cut through by a metre-gauge siding. These remarks refer only to stations outside Nagpur, for at that station, where the general workshops and stores of the railway are situated, a quasi-permanent system of mixed-gauge sidings had to be provided.

Stations.—The work at stations consisted in providing passenger and goods platforms; the metre-gauge platforms, where these existed, being invariably so situated as to require removal. Five goods sheds, which were heavy structures of teak framing with tiled roofing, had to be dismantled and re-erected, and new road approaches made to most of the goods platforms.

Station Machinery.—Signals, home and distant, had to be taken down and re-erected on fresh sites, at eighteen stations. All existing ash-pits were dismantled, and twenty new ash-pits built The water-tanks at ten stations were raised from 3 to 4 feet so as to

same time increased 50 per cent. The existing water-columns were all used, but it was necessary to take them down and re-erect them on fresh sites. All piping had to be re-laid. New buffer-stops, stop-blocks, and loading-gauges were required at all the stations. Two engine turntables, each 50 feet in diameter, were provided at the engine-sheds, in place of turntables 35 feet in diameter, and one of 50 feet at an intermediate station where a triangle was formerly used. Two carriage-traversers were supplied in place of metre-gauge traversers.

Engine-Sheds.—There were two engine-sheds, one at Nagpur and one at Dongargarh, 126 miles from Nagpur; the former, on account of its cramped situation, could not be used, and an entirely new shed, ash-pits, and yard had to be provided. At Dongargarh the existing shed and water-tanks were utilized; one line of ash-pits for the standard-gauge being substituted for two lines of metre-gauge ash-pits, and another shed, containing a double line of ash-pits, was added.

Workshops.—Although considerable additions were required in the general workshops and stores at Nagpur, these were necessitated by the extension of the railroad, the arrangements and appliances provided for the metre-gauge line being quite sufficient for one standard gauge of the same length.

Rolling-Stock.—It is a matter of difficulty to ascertain with any degree of certainty what proportion of standard-gauge locomotives, and rolling-stock of the various descriptions, should be considered as equivalent to those with which the line was equipped at the time it was closed to metre-gauge traffic. A separate abstract has been made showing in full detail the proportions taken, the cost of each unit of the standard-gauge stock, the total cost of the same, and the credit value of metre-gauge stock. The average speed of trains has been considered to be the same for both gauges.

Statement of Cost.—An abstract of this in tabular form is attached, giving details of the expenditure, both in England and in India, and the approximate credits for metre-gauge materials. The English and Indian expenditure have been kept separate for the sake of greater accuracy in the expenditure, which has all been accounted for in India in rupee currency. All sums actually disbursed in England in sterling money were charged to works in India in rupees, at the current rates of exchange, whereas money spent or received in India was, under the terms of the company's contract, considered to have passed through the hands of the Secretary of State, and

was refunded in England, by the company, at a fixed rate of Rs.13 to the £1 sterling. The whole of the expenditure on works has therefore been converted from rupees into pounds sterling as follows:—

English expenditure at 1*s.* 4½*d.* per rupee, or Rs.14·54 per £1 sterling, the average rate current in 1887–1888; Indian expenditure at Rs.13 per £1 sterling.

The actual capital cost of the Nagpur-Chhatisgarh State Railway, as taken over by the Bengal-Nagpur Railway Company, was Rs.116,44,910, and adding to this Rs.56,38,501, the cost of conversion to the standard gauge, the total cost to the company of the converted line has been Rs.172,83,411 or Rs.1,18,786 per mile.

The works described in this Paper have been carried out under the orders of Mr. T. R. Wynne, Agent and Chief Engineer of the railway.

The Paper is accompanied by three tracings.

Table I.—Abstract of Bridge-work.

Bridge.		Details of work done.		Number of Bridges of each Class.
Class.	Span in feet.	Requiring diversion of line.	Not requiring diversion of line.	
Girder	150	One bridge of nine spans (Weingunga) masonry of abutments and piers altered, new girders supplied.	Nil.	1
"	60	Two bridges, each of one span, built new to replace old bridges affording insufficient waterway.	One bridge of one span divided into two spans of 28 feet by building a masonry pier in the centre of the span.	
"	"	One bridge of seven spans, masonry considerably altered and new girders supplied.		
"	"	One bridge of five spans, masonry considerably altered and new girders supplied.		
"	"	Two bridges of three spans, masonry considerably altered and new girders supplied.		
"	"	Two bridges of two spans, masonry considerably altered and new girders supplied.		
"	"	Three bridges of one span, masonry considerably altered and new girders supplied.		12
			Total bridges carried over	13

ABSTRACT OF BRIDGE-WORK—*continued.*

Bridge.		Details of work done.		Number of Bridges of each Class.
lass.	Span in feet.	Requiring diversion of line.	Not requiring diversion of line.	
			Total number of bridges brought over.	13
Girder	40	Two bridges, each of one span, built one new to replace bridge dangerously cracked and shaken; one to replace old bridge affording insufficient waterway.	Nil.	
,,	,,	One bridge of four spans, masonry altered, new girders supplied.		
,,	,,	One bridge of three spans, masonry altered, new girders supplied.		
,,	,,	Two bridges of two spans, masonry altered, new girders supplied.		
,,	,,	Nine bridges of one span, masonry altered, new girders supplied.		15
,,	20	One bridge of three spans increased to five spans to provide additional waterway, old masonry altered and new girders supplied to old spans.	Fifteen bridges, each one span, masonry altered and new girders supplied.	
,,	,,	Three bridges, each one span, built new to replace old bridges dangerously cracked.		
,,	,,	One bridge of one span, heavy repairs done to masonry and new girders supplied.		20
,,	13	Nil.	One bridge of two spans, masonry altered and new girders supplied.	2
,,	,,		One bridge of one span, masonry altered and new girders supplied.	
			Total bridges carried over	50

Bridge.		Details of work done.		Number of Bridges of each Class.
Class.	Span in feet.	Requiring diversion of line.	Not requiring diversion of line.	
			Total number of bridges brought over.	50
Girder	12	Eleven bridges, each of one span, built new to replace old bridges dangerously cracked and shaken.	Thirty-three bridges of one span, masonry altered and new girders supplied.	44
,,	10	One bridge of one span, built new to provide additional waterway.	Nil.	1
,,	8	Nil.	One bridge of one span, masonry and existing girders altered.	1
,,	6	Sixteen bridges, each of one span, built new, fifteen to replace old bridges dangerously cracked and shaken, one to provide additional waterway.	One bridge of one span, built new to carry siding in station yard.	
,,	,,		One bridge of one span, lengthened to carry two lines in station yard.	
,,	,,		Forty bridges, each of one span, masonry altered and new girders supplied.	58
,,	3	Nil.	Nine bridges, each of one span, masonry altered and existing girders altered.	9
Open-topped	1½ and 2	One bridge of two spans, built new to provide additional waterway.	Twenty-two bridges of one span each, masonry altered.	23
			Total bridges carried over	186

ABSTRACT OF BRIDGE-WORK—*continued.*

Bridge.		Details of work done.		Number of Bridges of each Class.
Class.	Span in feet.	Requiring diversion of line.	Not requiring diversion of line.	
			Total number of bridges brought over.	186
Arch	30	Nil.	One bridge of two spans, and one bridge of one span, masonry slightly altered.	2
,,	20	Nil.	One bridge of one span, masonry slightly altered.	1
,,	15	Nil.	One bridge of one span, masonry slightly altered.	1
,,	12	Nil.	One bridge of one span, masonry slightly altered.	1
,,	10	Three bridges, each of one span, built new in deviations of line . .	Fourteen bridges of one span, masonry slightly altered.	17
,,	6	Three bridges, each of one span, built new in deviation of line . .	Nineteen bridges of one span, masonry slightly altered.	
		One bridge of one span, built new to provide additional waterway .		23
,,	5	Nil.	Two bridges, each of one span, masonry slightly altered.	2
	4	Nil.	One bridge of one span, masonry slightly altered.	1
,,	3	Three bridges, each of one span, built new, two in deviations of line, one to provide additional waterway .	One bridge of one span, converted from a girder bridge, 6-feet span.	
			Eighteen bridges of one span, masonry slightly altered.	22
Barrel-drains and pipe-culverts	..	Nil.	Thirty-five built new for irrigation channels.	
			Seven converted from small girder or open-topped bridges.	
			Nineteen, masonry altered.	61
			Total number of bridges	317

TABLE II.—LOCOMOTIVES.

Metre-Gauge.					Standard Gauge.	
Class.	Number on Line.		Gross load at 15 miles an hour in Tons.	Number × Load.	L Class Engines, Gross load at 15 miles an hour, 720 tons.	Cost at Rs. 36,200 each.
						Rs.
B	2	27	150	300	..	..
F	14[1]		300	3,900	12	4,34,400
Fa	5		350	1,750	..	..
C	6[2]		250	1,250	..	..
Deduct approximate value of Metre-Gauge Locomotives . .						3,33,967
Net cost of Standard Gauge Locomotives.						Rs.1,00,433

[1] Engine considered as used for shunting only.

[2] Two Standard-Gauge engines allowed as the equivalent of two Metre-Gauge engines for shunting.

TABLE III.—CARRIAGE AND WAGON STOCK.

Metre Gauge.				Standard Gauge.				
Description.	Number Line.	Carrying in Capacity or Seats.	Capacity and Number.	Description of Equivalent.	Capacity.	Number.	Cost of One.	Cost.
							Rs.	Rs.
First-class carriages	5	8 seats	40	Composite First- and Second-class carriages	9 seats	14	8,551	1,19,714
Second-class carriages	2	10 „	20					
Composite carriages First and Second class	11	9 „	99					
Intermediate-class carriages	10	26 „	260	Third-class carriages, some containing Intermediate-class compartments	50 „	32	4,742	1,51,744
Third-class carriages	37	36 „	1,332					
Horse boxes	4	4 horses	16	Horse-boxes	6 horses	3	4,862	14,586
Covered goods wagons	422	5·63 tons	2,376	Covered goods-wagons	10¾ tons	211	2,403	5,07,033
Low-sided and ballast wagons	315	6 tons	1,890	Low-sided goods-wagons	11½ „	172	1,848	3,17,856
Powder vans	2	5 „	10	Powder-vans	10 „	1	3,459	3,459
Timber trucks	8	6 „	48	Timber-trucks	12 „	4	2,540	10,160
Carriage trucks	3	1 vehicle	3	Carriage-trucks	12 „	3	2,680	8,040
Cranes, 10-ton travelling	4	10 tons	40	Cranes, 10-ton travelling	10 „	4	7,644	30,576
Break vans	24	..	24	Break vans	10 „	16	4,187	66,962

	Rs.
Total cost of standard-gauge carriage and wagon stock	12,30,130
Deduct approximate value of metre-gauge carriage and wagon stock	6,32,425
Net cost of carriage and wagon stock	5,97,705
Add net cost of locomotives	1,00,433
Total net cost of standard-gauge rolling-stock	6,98,138

ABSTRACT OF COST OF CONVERTING METRE GAUGE RAILWAY TO INDIAN STANDARD GAUGE RAILWAY (145½ MILES).

Head.	Total Expenditure on Conversion.		Total Expenditure, English and Indian.	Probable Credits for Metre Gauge Materials.	Net Expenditure on Conversion.
	English.	Indian.			
	Rs.	Rs.	Rs.	Rs.	Rs.
Land	Nil.	32,297	32,297	Nil.	32,297
Earthwork . . .	Nil.	2,58,362	2,58,362	10,000	2,48,362
Bridgework . .	4,63,370	5,82,342	10,45,712	2,12,265	8,33,447[1]
Ballast	Nil.	4,12,032	4,12,032	Nil.	4,12,032
Permanent way .	27,60,143	10,04,110	37,64,253	8,28,156	29,36,097[2]
Stations . . .	Nil.	83,045	83,045	1,000	82,045
Station machinery	68,109	79,918	1,48,027	35,195	1,12,832
Engine-sheds . .	Nil.	79,403	79,403	Nil.	79,403
Rolling-stock . .	13,35,213	3,29,317	16,64,530	9,66,392	6,98,138[3]
Tools and plant .	Nil.	65,532	65,532	Nil.	65,532
Establishment .	19,044	1,19,272	1,38,316	Nil.	1,38,316[4]
Totals in rupees .	46,45,879	30,45,630	76,91,509	20,53,008	56,38,501
Totals in £ sterling	319,524	234,279	553,803	157,923	395,880

Cost, per mile, of conversion . . . . Rs. 38,752
" " " £2,721

[1] In the case of bridges rebuilt, or of which the waterway was increased, a portion only of the expenditure, equal to the cost of conversion, has been included.

[2] The probable credit for metre-gauge materials appears small, but the wooden sleepers were almost of no value; a large proportion of fastenings were broken, and the sale price fixed for sound rails is only 75 per cent. of the present cost price.

[3] The probable credit for metre-gauge rolling-stock seems rather high, but it must be noted that all stock was put into thorough repair before sale.

[4] Includes portion of charges for "direction."

(*Paper No. 2487.*)

"Timber in the Tropics; the Teredo Navalis and White Ant."

By John William James, M. Inst. C.E.

There appears to be some misconception with regard to the ability of certain Australian timbers to resist the attacks of the teredo navalis and the white ant, and the Author desires to put on record his experience with these and other descriptions of timber during a residence of about six years at Port Darwin, where he was superintending-engineer for the South Australian Government. He had under his control the construction of a line of railway from the Port to a point of 146 miles inland, and of a jetty in connection with the railway, 1,120 feet in length, which extended into the water 38 feet below low-water of ordinary spring tides. This jetty was constructed of West Australian timber, the piles (of which there were 22,000 lineal feet) being karri.

In October, 1884, some jarrah piles, which had been put in as an experiment, were found, after an immersion of six months, to have been so seriously attacked by the teredo that it was at once decided to sheath all the timber in the jetty up to the high-water line with Muntz-metal. During ordinary spring-tides the water at Port Darwin rises 25 feet, thus necessitating the use of piles over 80 feet in length. They were driven to the rock—a soft mica slate—with a monkey weighing 2½ tons and falling 10 feet. Karri was found to be capable of withstanding this heavy driving better than jarrah, being larger in the fibre and more elastic; but experience has shown that for durability it is far inferior to the jarrah.

In order to protect the sheathing-metal on the fender-piles of the jetty from the chafing of vessels lying alongside it was found necessary to bolt timbers vertically on their outer sides, and the only material available at the time being karri, it was used as a temporary expedient, while an endeavour was made to obtain a sufficient quantity of a wood called "billian" (North Borneo ironwood), which had the reputation of being able to

resist the teredo in the tropics. After some delay a log of billian was procured, and a piece of it bolted to the jetty at the low-water line on the 2nd of November, 1886. This remained intact until it was examined in December, 1889, when no trace of the teredo could be found on it. Another piece of this timber was put in the ground in a place where white ants were numerous, and it was found after a year had elapsed to have been eaten in a few places, but without being materially damaged.

The temporary chafing-pieces of karri wood, which extended from the low-water line nearly to the deck of the jetty, were soon attacked, and after about three years completely destroyed at their lower ends by the teredo, the ravages of which extended to about half-way between the low- and high-water marks, there being very little damage higher up. They have since been replaced by billian timber. It is generally believed that the teredo dies after the wood in which it is concealed has been for about forty-eight hours out of water and exposed to the sun; but experience at Port Darwin proves that this is not so. When the temporary chafing-timbers were removed, portions of them were placed on the deck of the jetty, and the Author was present when, after about two months' exposure to the tropical sun, one of them was split up for the purpose of getting specimens of the teredo, several of which were taken out still living, although very weak. They appear to have the faculty of retaining the sea-water round them in their cells.

The white ants of Northern Australia are larger and much more destructive than those in the southern parts of Australia, or even in India. They attack growing timber, working through the heart of the trees from the root to the top, the only kind that effectually resists them being the cypress pine, which is on that account generally used for building purposes. It is, however, short-grained, and is not suitable for girders or for resisting heavy shocks; and as it is frequently found growing spirally, is not well adapted for planks or scantling. There is also an iron-wood—locally called ironbark, although it is not one of the eucalypti—which resists the white ant almost as well as billian, but seldom grows in such a shape as to be of commercial value. It seems to be more liable to injury by lightning than the trees among which it is found, so that little use is made of this timber, except for fence-posts, or stumps, on which the galvanized-iron and cypress-pine houses and stores of the Northern Territory are erected.

There are also two of the eucalypti, locally known as bloodwood

and paperbark, which withstand the white ant to some extent. The former is durable, but, having large gum-veins, will not make good sleepers, planking, or scantling, and the latter is not durable when subjected to the alternate action of the sun and atmospheric changes. The Author has also tested well-seasoned jarrah and sugar-gum sleepers; but in the course of a few months about a fourth of the timber had been eaten away by the white ants. A liquid named "Carbolineum Avenarius" having been recommended as a sure remedy, two sleepers, one jarrah, the other sugar-gum, were treated with it in accordance with the printed instructions, and were buried with two other untreated sleepers of the same kind in a place where these insects had free access to them. In about two months the two untreated sleepers were badly eaten, whereas the two treated with carbolineum were almost intact. These latter were again placed in the ground and left undisturbed for several months, and when they were taken up it was found that the white ants had eaten away a quantity of the wood and were making their way right through it. Another compound named "Anti-Termite" was tried with similar results, so that it would seem that though such remedies may check the destruction of the wood for a time, they soon lose their efficacy in a tropical climate. New South Wales ironbark, which is considered one of the finest timbers of the country, and Western Australian karri, are incapable of resisting the attacks of the Northern Territory white ants. Jarrah sleepers have been much used on the South Australian railways, and have the highest reputation for their ability to withstand the termites of that colony; but in the Northern Territory jarrah is as readily attacked as any of those timbers that are considered inferior in that respect in the south. It may therefore be inferred that the teredo navalis also may be less aggressive in colder places than in the warm waters of the tropics, and that it is owing to this that jarrah has gained its reputation, but that karri is not likely to resist sea-borers anywhere.

The question of sleepers for the railway from Port Darwin—the Palmerston and Pine Creek Railway—being undecided, the Author applied to the Java Public Works Department, and through the courtesy of the Engineer-in-Chief of the Java State Railways, was informed that a timber known as tatti-wood, a sort of teak growing in that island, was the only wood used there for railway sleepers; that it gave great satisfaction, was very durable, and that the white ants never attacked it when in use on the railway lines, the disturbance caused by passing trains being a sufficient pro-

tection; but that sleepers in stock were liable to destruction unless precautions were taken, and for this reason they were so stacked that a man might go underneath to examine them, and clean out the ground, which was done about once a week. But as a suggestion was made at the same time that jarrah, or any timber that had been found capable of resisting the white ant in other parts of Australia, would be suitable for the Northern Territory, it may be inferred that the white ant is not so destructive in Java as in North Australia.

In 1886 Captain Maclear, commanding H.M.S. "Flying Fish," brought to Port Darwin four logs of timber from the Celebes Islands, and handed them over to the Author in order that their powers of resisting the teredo and the white ant might be tested. These logs were described as follows by the late Rev. J. E. Tenison Wood, who at the time was visiting Port Darwin :—

"1. 'Kajoe Bessi' (*Erythroxylon*), or ironwood. Very hard, and "lasts long; much used by the government for building bridges, "piers, houses, &c. Can be procured up to 60 feet long and 1 foot "thick.

"2. 'Kariskes' (*Mimusops*). A very hard wood, which resists "the action of water, and can be procured up to 90 feet long and "1 foot thick.

"3. 'Possi Possi' (*Sonnerata Acida*), or Malay River willow, "though not a true willow. Can be procured up to 60 feet long "and 1 foot thick.

"4. 'Tring.' Two mangrove trees are called by this name "(*Bruguvera* and *Rhizopora*). Both are found in Australia, and "can be procured up to 120 feet long and 9 inches thick. The "three latter are very good long-lasting kinds, much used for "waterworks."

On the 21st of July, 1886, a piece of each of these Celebes timbers was sunk in the harbour, and four other pieces were placed on the surface of ground infested by white ants, and covered with the refuse of timber that had been already destroyed by these insects. The first were brought ashore on the 26th of November, when they had been over eighteen weeks in the water, and from notes taken at that time, the Author finds that the teredo had bored into the "Kajoe Bessi" and the "Kariskes" from the sides where the sapwood remained; the "Possi Possi" was intact, except at the heart, where decay had commenced; the "Tring" was also attacked in the heart, which showed symptoms of decay, and was perforated at the sides, but not to such an extent as the "Kajoe Bessi" and "Kariskes," all four timbers appearing to resist the

teredo better than either jarrah or karri. The four pieces placed on the ground were examined on the 3rd of November, having been fifteen weeks undisturbed. The "Kajoe Bessi" was intact; but the white ants had made some progress in the destruction of the other three. They were then buried in the earth, and were allowed to remain undisturbed for twenty-five weeks, at the end of which time it was found that all of them had been attacked, the "Possi Possi" and "Tring" having offered less resistance to these insects than the "Kariskes," though this latter was much eaten. The "Kajoe Bessi" was altogether the best of the four, as, although the white ants had penetrated it, they had made very little progress with its destruction.

So far as the Author's experience has extended, the only native timber brought under his notice that is really suitable for buildings and public works in the Northern Territory of Australia is the cypress-pine, which resists the attacks of the teredo and white ant, though the latter will strip the sapwood from it. As already stated, it will not stand heavy shocks or severe transverse strains.

(*Paper No. 2493.*)

"The Carrara-Marble District Railway."

By Charles Preller Sheibner, Ph.D., Assoc. M. Inst. C.E.

This railway was completed in May 1890, and owing to the peculiar nature alike of its alignment and of its traffic, presents several striking features. The Carrara district is situated between Spezzia and Leghorn on the Mediterranean seaboard, on which it has four shipping-places provided with large storeyards, wharves, piers, and cranes. In addition to these facilities for the export of the marble, the Mediterranean trunk railway which skirts the coast, has, within a distance of about 20 miles, six stations and extensive storeyards. The principal towns are Carrara, Massa, Seravezza, Pietrasanta, Camajore, and Viareggio, which, including the villages of the neighbourhood, contain in the aggregate, upwards of 160,000 inhabitants over an area of about 200 square miles; so that, as regards density of population, the district compares with several of the populous mining-districts of England and Wales.

Geological Features.

The range called the Apuan Alps, more commonly known as the Carrara mountains, is an offshoot of the Apennines trending from N.N.W. to S.S.E., and consists of a series of sharply-defined peaks, the highest of which, in the centre of the chain, rises to about 6,000 feet above sea-level, the whole range presenting in its outline the form of an elliptic dome. Early geologists held that the extensive amygdaloidal beds of marble, which rest on paleozoic schists, were of igneous origin; but organic remains, discovered in the series of stratified and sharply-twisted anticlinal folds characteristic of the range, have led to the conclusion that the marble of the Carrara district is triassic limestone whose present saccaroidal or crystalline state is due to lateral and super-incumbent pressure under high temperature. The stratigraphical structure of the range is as follows:—

	Feet.
Paleozoic (permian) schists, about	4,000
Semi-crystalline (lower trias) limestone, called "Grezzoni"	1,500
Saccaroidal limestone (trias) or marble strata	3,500
Semi-crystalline (upper trias) limestone, called "Cipollini"	2,000
	11,000

It is thus seen that the marble strata proper, which cover an area of about 80 square miles, and yield besides the pure white marble, the grey (bardiglio), the veined (fiorito), and the many-coloured (breccia) varieties, reach in places to the enormous depth, measured vertically, of $\frac{3}{4}$ mile, as is shown by the outcrops, by the terraced quarries, and by the sections recently laid open in the cuttings and tunnels of the railway. The supply of marble for ornamental and building purposes of all descriptions is therefore practically inexhaustible.

Working of the Quarries.

The marble district is divided into three sections called the Carrara, Massa, and Seravezza divisions, from the three parallel valleys so named which run at right-angles to the crest of the range towards the seaboard, Fig. 1, Plate 11. All the quarries—some of which were worked by the Romans as early as 200 B.C., as is attested by inscriptions discovered on the spot—are surface-workings at an altitude of from 700 feet to 2,000 feet, and in some cases, *e.g.*, the Monte Altissimo quarries in the Seravezza division, which yield the finest statuary marble of the whole district, 3,000 feet above sea-level. They are situated for the most part in the deep gulleys of the range, and the marble debris produced in the blasting and dressing operations is thrown down the mountain sides, where it has accumulated for centuries in immense quantities, and is a fruitful source not only of inconvenience and litigation but frequently of danger. The blocks of marble, which average 10 tons, weigh sometimes as much as 40 tons and contain 500 cubic feet, the weight of Carrara marble being 2·8 metric tons per cubic metre = 0·081 English ton per cubic foot. They are let down from the quarries on rough inclined planes by means of runners, cross-beams, and ropes twisted round equidistant fixed poles, Fig. 3, Plate 11, to the loading-stages of the railway, or of the bullock carts, whence they are conveyed either to the saw-mills situated in the lower valleys, or to the storeyards at the railway

stations and shipping places. Various experiments have been made from time to time, with a view of substituting mechanical contrivances for this slow and often dangerous process of sliding the blocks down; but the multiplicity of these inclines scattered over a large number of quarries, no less than the high motive- and brake-power required for such heavy loads on gradients varying from 10 to 50 per cent., and the consequently excessive outlay that would be required for the introduction of these methods, have hitherto greatly militated against their adoption. The Author has recently proposed an effectual and comparatively inexpensive appliance for this purpose, to which reference will be made hereafter.

The annual output of the quarries in the three divisions averages about 150,000 tons at Carrara, 20,000 tons at Massa, and 35,000 tons at Seravezza; it should, however, be added that the various operations of sawing and working the marble often produce a double, and in some cases treble local traffic.

Saw-Mills and Polishing Works.

The number of saw-mills is seventy-five in the Carrara, thirty in the Massa, and forty-five in the Seravezza division, with three hundred and thirty-five, one hundred and fifty, and two hundred saw-frames respectively, making a total of six hundred and eighty-five saw-frames. These mills, most of which are driven by water, some by gas-engines and some by steam, work, as a rule, day and night throughout the year. The saw-frames are constructed for blocks up to 10 tons or about 125 cubic feet; they require each about 4 HP., and consume 100 tons of sharp sand in cutting from 150 to 200 tons of marble into slabs whose thickness varies according to the number of saw-plates. The total water-power used in the district for this purpose is about 3,000 HP., and the total output of sawn slabs amounts to upwards of 100,000 tons per annum. Irrespective of the saw-mills, there are about one hundred and thirty polishing works for ornamental and building purposes generally. At first sight, the district would seem to offer a remunerative field for the introduction of electric motive-power; but the water-power is obtained so cheaply, the royalty paid to the State for its use being at the rate of 4*s.* per HP. per annum, that under existing conditions, electricity could not compete with it.

Viareggio Sand Excavations.

The sharp, heavy, white, and almost purely siliceous sand used in the sawing of marble is obtained exclusively from extensive subaqueous beds near Viareggio, Fig. 1, Plate 11. These deposits, formed by the disintegration of the hard sandstone (macigno) strata which now bound the northern banks of the lake of Massacciucoli, near Viareggio, and at one time extended to the sea-shore, cover a superficial area of upwards of 1,600 acres, and are about 42 feet in depth; thus representing an available supply of over 100 million cubic yards, or 105 million tons (the specific gravity being 1·4. The sand is got by manual labour, with long spoons, about 230 tons per day or 70,000 tons per annum being excavated to the full depth of the deposits. It is then taken in barges (by canal) to the Viareggio wharves, a distance of less than 2 miles, where it is unloaded, and conveyed chiefly by rail, but to some extent by bullock-carts and also by sea, to Seravezza, Massa, and Carrara. Here, too, as in many similar cases in Italy, the cheapness and abundance of labour, the high cost of coal, and the fact of the operations being carried on simultaneously in no fewer than ten pits instead of being concentrated at one point, militate against substituting mechanical for manual labour.

The dredging is at present performed by forty-two men, who take fourteen empty barges (about 17 tons capacity each), with dredging apparatus on separate boats, from Viareggio up to the pits in one hour, raise about 240 tons of sand in three and a half hours, returning with the loaded barges down to Viareggio in one hour, and unloading the sand at the wharves in two and a half hours, making a total of eight hours' actual work, their wages being 2.25 liras, or 1*s.* 10*d.* per day. The spoons hold 140 kilograms of sand each; the operation of dropping, filling, raising, and emptying occupying one and three-quarter minute; hence the quantity raised by each spoon per hour is 4·9 tons; or by fourteen spoons working simultaneously in the different pits = 68·6 tons, total in three and a half hours = 240 tons. The comparative cost of dredging therefore works out as follows:—

(1.) By Manual Labour:—

	Liras.
Wages of forty-two men for $3\frac{1}{2}$ hours' work = ...	46.20
Interest and wear and tear on 14,000 liras (the cost of the fourteen barges and tools), at 10 per cent. per annum .	4.70
	50.90

$$\text{Cost of dredging} = \frac{50.90 \text{ liras}}{240 \text{ tons}} = 21 \cdot 2 \text{ cent.} = 2 \cdot 04d. \text{ per ton.}$$

(2.) By Steam-Dredger of the Priestman "B" type of 8 HP.

	Liras.
To raise 240 tons at the rate of 35 tons per hour takes 7 hours; navigating between the pits, etc., 1 hour; total 8 hours. Hence, the quantity of coal consumed at 5 kilograms per HP. per hour is 320 kilograms, costing at 40 liras per ton	12.80
Oil and repairs	3.00
Interest on £800, the cost of the machine, at 10 per cent. per annum, including wear and tear	6.00
Interest and depreciation on fourteen barges at liras 800 each	3.70
Wages: one man on the dredger	5.00
Fourteen men for the barges, 1.50 lira each.	21.00
	51.50

$$\text{Cost of dredging } \frac{51.50 \text{ liras}}{240 \text{ tons}} = 21 \cdot 42 \text{ cent.} = 2 \cdot 06d. \text{ per ton.}$$

It is thus seen that while the cost is practically the same in both cases, the forty-two men do the work in three and a half hours, whereas the steam-dredger requires eight hours, or more than double the time. A considerable saving could be effected if the sand were discharged by the buckets of the steam-dredger direct into the trucks.

Exports of Marble.

According to the official statistics annually published by the Carrara Chamber of Commerce, the mean exports of marble in blocks, in slabs, and polished during the last decade to all parts of the world amount to 133,000 tons from Carrara and Massa, to which must be added the exports from Seravezza, 30,000 tons, making a total of 163,000 tons per annum. The maximum was reached in 1887, when the exports were: Carrara, 166,000; Massa, 20,000; and Seravezza, 40,000; total, 226,000 tons, irrespective of the marble used in the district itself. Moreover, the debris is largely employed for masonry and road-metal, and when powdered,

is used in the manufacture of artificial mineral water, the white marble containing over 90 per cent. of carbonate of lime. The value of the annual exports averages 100 liras, or £4, per ton, amounting to upwards of £670,000. At Carrara the Municipal Corporation levies a toll varying, according to quality, from 1 to 5 liras per ton on the output of the quarries, the annual revenue accruing therefrom amounting, on an average, to £12,000, part of which sum goes towards keeping in repair the marble roads, the cost of maintenance of these being, throughout the district, from £60 to £100 per mile.

Marble Railway.

The total length of the line from the sea to the quarries is 25·6 kilometres (16 miles), including the section from Avenza to Carrara, which forms part of the Mediterranean railway system, but over which the Marble Railway Company has running powers. The length of the Marble Railway proper is therefore, including branches, 20·6 kilometres (13 miles), of which the first or lower section of 7 miles was opened in the year 1873. Owing to financial difficulties, arising out of the onerous terms of the concession imposed by the Carrara Corporation, the second or mountainous section of 6½ miles was not commenced till 1887, being completed in May, 1890. The loading-stages of the principal quarries (Crestola, Piastre, Canal Bianco, Para, Fantiscritti, Canal Grande, Ravaccione, Colonnata and Gioja), Fig. 2, Plate 11, are situated at altitudes varying from 876 to 1,492 feet, and at comparatively short distances apart, but are separated from each other by steep ridges rising up to 3,000 feet above sea-level. At first sight the idea would naturally suggest itself of running a separate branch up to each quarry from Carrara, following the ancient watercourses now occupied by the bullock-cart roads; but this would be impracticable owing to the rapid rise of the ground, necessitating grades up to 15 per cent., on which even a combined adhesion and rack-engine would only push a load equal to its own weight. Rope-traction on inclined planes would have involved placing a stationary engine of 150 HP. in each of the nine quarries, which, moreover, are almost destitute of water; and hence the only practicable and adequate alignment of the mountainous section, with grades of from 4 to 6 per cent., to be worked by ordinary adhesion, was that of a series of reverse stations, as illustrated by Fig. 4, Plate 11.

The grade of 4·5 per cent. is tolerably uniform throughout the ascent of 1,207 feet from Carrara to the summit-level at Ravaccione, Fig. 5, Plate 11. It increases to 5 and 6 per cent. near the Colonnata terminus, and the two safety sidings near Miseglia and Tornone have a grade of 7 per cent. The minimum radius of curvature is 5 chains and the maximum 9 chains, with the exception of one of 50 chains, and the shortest straight length between reverse curves is 11 yards. About 2 miles, or 40 per cent. of the entire length of the mountainous section, is in curves. The works throughout are very heavy, there being fifteen tunnels, with a total length of 2·8 miles, and sixteen bridges and viaducts, while the remainder consists entirely of cuttings and sustaining walls from 16 to 46 feet in depth. This was rendered necessary not only by the nature of the ground and the high cost of land contiguous to the quarries, but by the loose masses of marble debris, which could only be avoided by extensive tunnelling. The tunnels have a cross-section of 39·4 square yards, and pass almost exclusively through the compact marble and limestone strata, which also yielded the material for the bridges and walls, as well as for the packing and ballast of the permanent way. The following was the mean cost of the work:—Tunnelling (without lining), £23 per lineal yard; excavation in cuttings, 4*s.* per cubic yard; dry masonry, 3*s.* per cubic yard; rubble masonry, 4*s.* 10*d.* per cubic yard; and ashlar masonry, 9*s.* per cubic yard. As many of the blocks are exported direct from the quarries, the line is constructed on the 4-foot 8½-inch gauge, with steel rails (Vignoles section), supplied by the Terni Steel Works, weighing 72 lbs. per yard, and 29·5 feet in length. They are fastened with three dogspikes and sole-plate to oak sleepers of 7·5 feet by 5·5 inches by 8 inches, there being ten of these to each rail length. The steel angle (suspended) fish-joints, which are 16 inches long, and weigh 32 lbs., make a joint as stiff as the rail itself. The depth of the rail is 13 centimetres; hence its moment of resistance $= 0·07 \times 13^3 = 154$ centimetres (3·31 inches) and the greatest load it can bear between sleepers, 2·96 feet apart, from centre to centre, taking the tensile strain at 7·3 tons per square inch, is 15·5 English tons. The permanent way is, therefore, not inferior to that of the trunk lines crossing the Alps and Apennines. The maximum load of engines and trucks is 7 metric tons per wheel; hence the greatest strain to which the rail is subjected is $7,000 \times \frac{90}{8} \times 154 = 510$ kilograms per square centimetre (3·1 English tons per square inch). The cost of the rails, delivered on the line, was £8 16*s.* per English ton; that of the

sleepers, 4*s*. 9*d*. each, and the total cost of the permanent way, 26*s*. 4*d*. per lineal yard. The total actual cost of construction (including land and compensation) of the whole line of 13 miles was £320,000, which, with £20,000 of rolling stock, amounts to £26,158 per mile, exclusive of financial charges and interest. The making of the mountain section occupied two years and a half, the contract being carried out by the Venetian Public Works Company of Padua.

The lower section, from the sea to Carrara, is worked by two four-wheeled Krauss tender-engines of 25 tons, and the upper section by two six-wheeled (coupled) Krauss engines of 34 tons when full, the two last named being fitted with Riggenbach air-brakes, the cost, inclusive of duty and carriage, being £1,200 and £1,600 respectively. The company owns, for local and through marble traffic, seventy-four four-wheeled trucks; twenty-six of which carry 10 tons, eight carry 15 tons, and forty take a load of 20 tons, and two six-wheeled trucks which serve to transport blocks up to 28 and 36 tons respectively. They are fitted with powerful screw-brakes, and are of special construction, their weight being only one-third, and in the case of the six-wheeled trucks one-fourth of the load they carry, the length of the platform varying from 13 to 16·5 feet, the width being 7 to 8 feet. The rigid wheel-base is in all cases 8 feet, so as to enable the trucks to pass the sharpest curves. Blocks of exceptional dimensions for colossal statues or monuments up to 40 tons are carried on two 20-ton trucks, in the centre of which cross-beams are pivoted, with rails laid upon them so as to form a platform; but for blocks exceeding 40 tons special trucks have to be built. The 20-ton trucks were nearly all built by the Bristol Wagon Company, and have given the most satisfactory results; whilst some new ones on the same model have lately been supplied by Messrs. F. Grondona and Co., of Milan, the cost being £130. They have a short platform which has been found to be of great advantage, whereas the 15-ton (six-wheeled) and the 25-ton (eight-wheeled, on two bogies) through-traffic marble-trucks of the Mediterranean Railway Company, the platforms of which are 23 and 33 feet long, do not answer so well, that of the former being liable to bend at the ends owing to the great overhang, and that of the latter in the centre, from the bogies being too far apart. The 34-ton engines which work the steep gradients have the following leading dimensions:—diameter of the cylinders, 40 centimetres (15·7 inches); length of the stroke, 60 centimetres (23·6 inches); diameter of the driving-wheels, 108 centimetres (42·5 inches); pressure in the boiler, 170 lbs. per square inch; hence their effective tractive force at half-pressure is 4,860 kilo-

Taking the resistance of the train on sharp curves at 1
per ton, the engine should and does haul, exclusive of its

and under ordinary conditions, $= \dfrac{4860}{\text{grade per mile} + 1}$
on the different gradients :—

			Tons.
On 3 per cent. gradient			87
„ 4	„	„	63
„ 4·5	„	„	54
„ 5	„	„	46
„ 6	„	„	36

During wet weather, or frost, these loads have to be
10 per cent. The engine then hauls or pushes on the 4
eight empty 20-ton trucks, or a load of 48 tons,
of 2·8 metres per second, the resistance it overc
therefore $(48 + 34) \times (45 + 10) = 4{,}510$ kilograms,

coefficient of adhesion is reduced from one-seventh

one-eighth, while the power developed is $\dfrac{4{,}510 \times 2\cdot 8}{75}$
The engine takes down the incline, under favourable
fifteen full trucks, or 390 tons, and covers about 100
($62\frac{1}{2}$ miles) per day, of which two-fifths are traversed i
at reverse stations and quarries, the consumption of
per ton, being about 1 ton per day of ten hours' work.

The working expenditure of the line is considerab
by the fact of the Company, in order to secure the t
obliged not only to keep a large number of bullocks fo
the material to the saw-mills, and at the storeyards,
work some of the inclined planes. Before the new
opened, the cost of this, and of cartage by one hundr
amounted to over £8,000 per annum, equal to more t
cent. of the entire working expenditure, which represe
90 per cent. of the gross earnings. Since then this ite
reduced to about one-half; but although the rates are
tive *per se*, the mean rate being 50 centimes per ton pe
($7\frac{1}{2}d.$ per ton per mile), including loading and unlo
clear that the working expenditure cannot be brought
65 per cent., until all the accessible quarries, saw-mills
yards have been connected by branches and sidings, and
working the inclined planes has been reduced. As r
last desideratum, the Author has recently designed a fo

trolley, or rack-engine, to be worked by six men, which will, by a series of pinions, transmit sufficient power to push, besides its own weight and that of the men, two empty trucks up an incline of 15 per cent. The inclines are laid on the ordinary gauge with a raised single central rack of the ladder type, in lengths of 100 metres alternating with short level stages, in order to rest the men. A pinion-wheel, with a powerful screw-brake acting upon it, will serve to retard or arrest the loaded truck on descending the incline, and the trolley will be provided both with a pinion and a slipper brake. The design is an adaptation of a similar but lighter machine, which has been worked for years on an incline of 6 per cent. in a stone quarry near Berne, in Switzerland. The cost of working short inclined planes in this way at Carrara will be about 1 lira per ton, against the present cost of 2 liras per ton, thus effecting a saving of 50 per cent.

A light railway (metre-gauge) of about 5 miles in length has recently been opened from Massa to the sea, while in the Seravezza division, a system of light railways on the same gauge, to be laid alongside the public roads, and to extend also to the sand-pits of Viareggio, has been approved by the Italian Government upon the surveys and designs made by the Author, and the works are now being carried out by the local authorities.

The Paper is accompanied by a tracing from which Plate 11 has been prepared.

(*Paper No. 2494, Abridged.*)

"Development of the Port of Swansea and Dredging a Deep Entrance Channel to Swansea Harbour."

By ROBERT CAPPER, Assoc. Inst. C.E.

THE history and condition of the Port of Swansea, up to the end of 1861, has been already fully described by Mr. James Abernethy, Past-President Inst. C.E., in his Paper on the "Ports of Swansea, Blyth, and Silloth,"[1] in 1862. At that period the South Dock had been recently opened on the right bank of the River Tarve, in front of the town; but since then the port has been largely developed by the construction of the Prince of Wales' Dock on the opposite bank of the river, opened for traffic in 1882, and the deepening of the approach channel. Swansea is the seat of the copper industry, and four-fifths of the metal trade of the country is manipulated there. Of the three principal mineral importing ports, Swansea stands first, with 417,834 tons in 1884; the mineral imports of Liverpool having only reached 213,626 tons, and of London 152,095 tons in the same year. There are also five hundred and sixty coal-pits within a radius of 40 miles. The development of the trade of Swansea since 1862 has been considerable, especially subsequent to about 1878; for the exports and imports, which amounted to 1,283,700 tons in 1862, reached 1,502,040 tons in 1878, and rose to 2,484,704 tons in 1885. The gross receipts, which were £38,892 in 1863, reached £58,356 in 1879, and attained £100,494 in 1885; whilst the ordinary expenditure was £15,097 in 1863, £23,199 in 1879, and £40,926 in 1885. At Swansea, as at other ports, the number and size of the steamers have notably augmented; the net tonnage having risen from 104,025 tons in 1865, to 305,780 tons in 1878, and 845,684 tons in 1885. The increase in the average size of the vessels leaving the port, and the decrease in the payment per ton, are given in the following Table :—

[1] Minutes of Proceedings Inst. C.E., vol. xxi. p. 309. A few additional details are given in the present Paper.

—	Registered Tons.		Average Payment per Ton.	
	1877.	1885.	1877.	1885.
	Tons.	Tons.	d.	d.
Coasting trade	89·75	111·97	4·59	4·06
Trade with Europe. . . .	201·05	362·65	7·22	6·22
Trade beyond Europe . . .	385·56	704·31	13·64	9·15

An Act was obtained in 1874 for the construction of the Prince of Wales' Dock, designed by Mr. Abernethy; and the works were commenced in 1879, under a contract with the late Mr. T. A. Walker. They comprised a dock of 23 acres, 2,300 feet long and 500 feet broad, with a minimum depth of water of 26 feet; a lock 500 feet long, with an intermediate pair of gates, 60 feet wide and having a depth of 32 feet of water over its sills at high water of ordinary spring tides and 24½ feet at neap tides; a tidal basin of 6¼ acres, 8 feet deeper than the lock sills, protected at its approach by an extension of the west pier, and by an east pier 1,210 feet long; and an embankment, sidings, hydraulic machinery, and electric lighting. The works generally are similar to those of the South Dock, described by Mr. Abernethy, and they cost £545,313, details of which are given in Appendix I. The piers are formed of timber encasing a hearting of rubble stone laid in courses; and the west pier, which is the most exposed, has piles 48 feet in length, and cost £30 per lineal foot. The coal-tips at the Prince of Wales' Dock, erected by Sir W. G. Armstrong and Co., are of the most improved type, and have occasionally loaded vessels at the rate of a truck of 10 tons per minute. The greatest shipments of coal in six consecutive days, at the three Great Western staithes, amounted to 11,630 tons 6 cwts. in 1885, and 11,886 tons 7 cwts. in 1886.

In constructing the docks of the Port of Swansea, the outer sills of their entrances have always been placed lower than the entrance channel to the port, in order that, as soon as the channel could be adequately deepened, they might be capable of admitting the trading vessels of largest draught at the periods when they were respectively constructed. Accordingly, the sills of the Prince of Wales' Dock lock, completed in 1881, were placed 6 feet lower than the bed of the entrance channel, and of Swansea Bay for 1¼ mile out to sea, which was then level with the deepest sill of the previous entrances. In order to render this depth on the lock sill

available for vessels, the approach channel required to be dredged for about 7,000 feet into the bay, to a depth of 14 feet, with a width of 200 feet at the top, and 150 feet at the bottom; and the material brought up had to be conveyed to a distance of 7 miles.

The dredging-plant of this port in 1881 consisted of an old single-ladder stationary dredger, a Priestman grab, and a self-propelling single-ladder hopper-dredger, which was quite inadequate to execute the extensive deepening works proposed. The hopper of the latter dredger was eventually removed, as the trips to sea of this dredger occupied too much of the available time. The formation of an entrance channel through the shoals in the estuary was commenced in 1881, with a dredger and five hoppers hired from the Tyne Commissioners, at the rate of £100 a week for the dredger and £9 a week for each hopper, the Swansea Harbour Trustees having to insure the whole plant, and the dredger not being allowed to ground. The voyage from the Tyne to Swansea, of 800 miles, was accomplished in seven days, the hoppers being each covered with a platform; and on the return journey, the well of the dredger was also closed at the top and bottom with planks. Work was commenced in Swansea Bay in May, 1881, twelve days after its arrival. Towards the end of July, it was removed to the old entrance channel; and left off dredging in October, one hundred and forty-nine days from its commencement, on the expiry of the six months of hire, during which period ten days were lost by the weather being too rough for the barges to remain alongside. The amount of material lifted and removed by this plant was 336,768 tons, at a total average cost of 10½*d.* per ton (see Appendix II). About 1,200 feet of channel had been cut in the bay when the work had to be stopped; and the trustees were only able to set to work again, with a dredger built expressly for them, in May, 1882, which completed the channel in May, 1885.

Details of the Swansea dredger No. 1 are given in Appendix III. It has double ladders, and dredges its own channel in advance; but in other respects resembles the largest of those used on the Tyne. Though in theory it could raise 944 tons an hour, the average performance in actual work was only 322 tons per hour. The greatest quantity raised by it in one day was 6,005 tons, and in a week 28,348 tons. The cost per ton lifted was from 3·525*d.* to 3·394*d.*, exclusive of interest on capital and depreciation, which would be about as much again (see Appendix IV). This is half the cost of dredging with a single-ladder hopper-dredger, and about 1½*d.* less than the dredging in the Tyne, which averages 4·94*d.* per ton. The consumption of fuel averaged 45 tons per week, and

22·23 lbs. per ton lifted. The material removed consisted of a mixture of mud, clay, and gravel, interspersed with boulders. The sides of the channel stand up like a wall in most places, though the material dredged varied in hardness, sometimes tearing off the backs of the buckets, whilst sometimes a sort of sandy silt ground away the working parts of the dredger. No rock was excavated, but buffalo horns and submerged oaks were often brought up; and, on one occasion, part of a vessel was lifted from a depth of 8 feet below the river-bed. Force pumps were provided for raising water to facilitate the passage of the dredged material down the shoots. The buckets were made of iron, with steel lips, semicircular in form, to avoid sticking in the ground, and with numerous holes for draining off the water carried up with them. Saddle-back hoppers were used for the conveyance away of the dredged material, having eight compartments carrying 40 tons apiece, or altogether 320 tons, fitted with side doors, so that on depositing the material on the beach, the hoppers rise and float off at once. The total amount of material lifted by the Swansea dredger and the other dredgers employed, between 1877 and 1885, is given in Appendix V.

The new channel formed by dredging affords a depth of 24½ feet at high water of the lowest neap tides, up to the docks, and an additional depth of 8 feet alongside the piers; so that ocean-going steamers can leave the port at fixed times, morning and evening, throughout the year. Moreover, the new channel maintains itself; and the increased scour which has resulted from its formation has deepened the river-bed about 4 feet; and the flood tide comes up an hour earlier than formerly. In 1875, vessels drawing 23 feet of water could only reach the port at extraordinary spring tides; whereas now vessels drawing 25½ feet, can come in at ordinary high water. The depth in the entrance channel is at present 42 feet at springs, and 35 feet at neaps. The volume of water inside the piers at high water, which amounted to 23 million cubic feet at springs, and 16 million cubic feet at neaps in 1866, attained 35 million, and 27 million cubic feet, respectively, in 1886. As a result of the deepening of the entrance channel, the shipping trade of the port increased 59·82 per cent. between 1880 and 1886, as compared with a general increase in British ports of 26 per cent. during this period. Moreover, whereas in 1880, no vessels went direct from the port to America, and only seven in 1881—as many as fifty-two went to America in 1886.

[APPENDIX.

APPENDIXES.

Appendix I.—Cost of Prince of Wales' Dock, and Other Works Undertaken in 1879.

	£
Dock, lock, basin, entrance channel and embankment .	247,958
Engineering and expenses of Act	22,129
Land and compensation	59,365
Railways	51,249
Transit sheds	6,665
West pier extension	29,443
East pier	34,769
Hydraulic machinery, cranes, &c.	38,048
Electric light	1,731
Canal, lock and basin.	7,699
Fresh water for shipping and boilers, culverts, roads, and water-pipes	6,283
Dredging new entrance channel	61,159
Commission on loans	3,860
Interest during construction	39,974
Printing, advertising, debenture stamping, and sundry disbursements	5,039
Total cost of dock, piers, and new entrance channel .	615,371

APPENDIX II.—TOTAL COST OF WORK DONE BY THE SELF-PROPELLING TYNE DREDGER, No. 5, VALUED AT £25,000, BUILT IN 1864, AND FIVE HOPPERS, VALUED AT £1,500 EACH, INCLUDING A GRATUITY TO THE CAPTAIN OF A HUNDRED GUINEAS.

—	£	s.	d.	£	s.	d.	Percentage of Cost per Ton lifted.
Cost of bringing dredger and barges round to Swansea, and taking back to Newcastle-on-Tyne, viz., 800 miles each way; towage, £800 and £1,200 .	2,000	0	0				
Insurance, £886 16s. 9d. and £667 4s. 1d.; 60 per cent.	1,554	0	10				
Wages, victualling boat, ropes, flooring, wells, &c.	1,664	2	3				
				5,218	3	1	3·71
Cost of dredger and barges while working, viz.:—							
Working expenses, weekly wages of crew; coal, 605 tons (or say, 29 tons a week), stores, &c.	2,700	1	1				1·93
Rent of dredger and barges	4,487	0	0				3·20
Towing barges and attending upon dredger	1,308	19	8				0·93
				8,496	0	9	
Maintenance, &c., viz.:—							
Repairs to chains, &c., for dredger . .	266	13	2				
,, ,, ,, barges . . .	215	19	2				
				482	12	4	0·35
Paid River Tyne Improvement Commissioners' claim for balance of standard cost of repairs over three years, averaging £4,000 per annum.				469	0	0	0·33
				14,665	16	2	10·45

Appendix III.—Description of Swansea No. 1 Dredger.

Hull, extreme length, 150 feet.
Breadth, moulded, 41 feet.
Draught of water (ladder down), 9 feet aft, 9 feet 6 inches forward.
Engine, jet-condensing, side-lever, marine type, 55 HP. nominal.
Two boilers, 17 feet long, 7 feet diameter.
Working pressure, 40 lbs. per square inch.
Capacity of bucket, 82 gallons = 13·12 cubic feet.
Length of ladders, 90 feet 6 inches.

	Two Ladders. Tons.	Cwts.	Qrs.	Lbs.
Tipping thirty-six buckets for each ladder per revolution in three minutes	47	4	2	4
Discharging per dredging day of fourteen hours	13,224	15	0	0
,, ,, week of seventy-seven hours	72,736	2	2	0

Capacity of hoppers, 240 yards, or 324 tons.

Cost of dredger	£27,500
Average cost of each hopper	£2,100

One Year's Work with Swansea No. 1 Dredger.

Percentages of Time Occupied.

Repairs to machinery and consequent stoppage	16·36
Coaling	1·30
Stoppages by traffic	0·16
Shifting links and pins	3·97
Shifting mooring chains	2·15
Extreme height of tides	1·35
Bad weather	16·50
Other delays	8·43
Time actually dredging	49·78
	100·00

The cost per ton lifted (exclusive of interest on capital) was as follows:—

	d.
Wages	0·969
Towage	0·979
Fuel	0·293
Maintenance and stores	0·991
Hoppers	0·293
Cost per ton	3·525

Appendix IV.—Cost of Working Swansea Dredger No. 1 during 1885.

	£ s. d.	£ s. d.
Wages		2,645 18 6
Towage		2,617 0 11
Fuel		895 18 8
Stores		161 14 9
Maintenance as per Stores Journal	320 9 8	
Bills	1,251 3 0	
Smiths and Fitters	380 12 9	
Pattern Makers	27 14 1	
Carpenters	58 13 10	
Joiners	7 1 3	
Masons	0 10 7	
Painter and Diver	0 18 1	
Labourers	67 12 9	
Haulage	19 17 6	
Timber, as per Carpenter's account	23 17 11	
		2,158 11 5
Hoppers	611 11 11	611 11 11
		9,090 16 2

Appendix V.—Material Dredged each Year, and also by each Dredger at Swansea.

Material Dredged Annually.

Year.	Tons.
1877	130,734
1878	96,052
1879	106,947
1880	107,689
1881	516,891
1882	309,672
1883	279,099
1884	709,103
1885	1,065,054
	3,411,241

Material raised by each Dredger.

	Tons.
Old dredger	578,845
Abertawe (Simons Builder)	1,042,048
Grab	70,492
"Number One"	1,151,470
Tyne dredger No. 5	336,768
Public Works Commissioners' "Briton"	192,903
Great Western Railway dredger	41,715
	3,411,241

OBITUARY.

ARTHUR WILDMAN BURNETT, second son of Mr. John R. F. Burnett, of South Hampstead, was born on the 10th of July, 1844, and was educated at Harrow.

He was articled for five years, from 1863 to 1867, to Mr. J. F. Latrobe Bateman. His great natural ability soon made itself evident, and Mr. Bateman, on the completion of his pupilage, engaged him as an assistant and entrusted him with important duties. He was chiefly associated with hydraulic engineering, and took part in the preparation of the scheme for supplying London with water from Wales, and also investigated the causes of the Shannon floods, and assisted in the designing of the works for the prevention of them. He was also engaged during this period as assistant in laying out and designing the Halifax, Dewsbury and Heckmondwike, Batley, Blackburn, Ashton Stalybridge and Dukinfield, and Dundee Waterworks, and others of minor importance. In 1867 he carried out a survey of the River Mersey at Runcorn, and in 1869 was appointed resident engineer on the Manchester Waterworks in the Longdendale Valley. This position he filled for four years, being occupied in finishing the construction of the works, and in surveying for the scheme for bringing the water of the Thirlmere Lake to Manchester.

In 1874 he was sent by Mr. Bateman to Ceylon to lay out a scheme and collect materials for a report on the supply of Colombo with water. On his return the following year he again went to Manchester, where he acted as principal assistant to Mr. G. H. Hill until 1882, when he accepted the post of Chief Resident Engineer at Colombo, under Mr. Bateman as consulting engineer, for the carrying out and construction of the waterworks for the Crown Agents of the Colonies. After overcoming great difficulties these works were finally completed in February, 1890.

The question of the water-supply of Colombo was first raised in 1866. Up to that time the inhabitants had depended upon wells, nearly every house having its own, in many cases close to the cesspit, so that the yield was very impure, and often brackish and unfit for drinking in the dry season. Two different sources from which

to procure the water were suggested, namely, to pump it from the Kelani River, at distances varying from 8 to 13 miles from the sea, according as the promoters of the different schemes considered that a greater or less distance would be necessary to ensure the water being fresh; or to bring it by gravitation from a reservoir in the Labugama Valley to a service reservoir in the town. The Kelani River scheme was for a long time most in favour, and in 1876 Mr. Bateman was instructed to prepare the working drawings for it. After further discussion, upon information supplied by later reports, it was decided almost at the last moment to abandon the Kelani pumping scheme and to proceed at once with the work of bringing the water in pipes from Labugama. Work was commenced in 1882, the stipulation being that it should be completed in three years. Delays took place in the prosecution of the contract, but at the end of September 1885 a temporary supply of water from a side stream near Labugama was brought in by the main pipe to Colombo. In October of that year the service tank gave way while it was being filled, and though it was repaired and strengthened during 1886 a second failure occurred in December of that year, and again in February 1887. The matter was then placed in the hands of Sir John Fowler, and under his instructions the work of restoration was begun in December 1888, and completed on the 9th of November, 1889, when the reservoir was successfully subjected to the full pressure. The storage reservoir at Labugama commands a drainage-area of 2,385 acres, the height of which is from 500 to 1,500 feet above sea-level, the average annual rainfall of the district being 161 inches. The reservoir has an area when full of 176 acres, with an available capacity of 1,233,000,000 gallons, the surface of the water being then 360 feet above sea-level. The embankment is 120 yards long at the top and its greatest height is 72 feet. The main-pipe, 20 inches in diameter, is 25 miles and 582 yards in length from its commencement in the straining-well at the Labugama reservoir to the gauging-tank at the top of the Máligákanda service-reservoir in Colombo, the total fall in the entire distance being 258 feet, or 10½ feet per mile. For a length of about 19 miles the pipe is carried over low-lying country at a height of from 5 to 25 feet, rising for short distances to 60 or 70 feet above sea-level; so that the pressure over a considerable portion of it is equal to a head of from 300 to 355 feet of water. On this account special valves are placed at intervals of about half a mile, in such a way that the shock of opening and closing is reduced to a minimum, and each length can be isolated if necessary for repairs.

The Máligákanda service-reservoir receives a continuous supply from the 20-inch main, and delivers it to the town through two others of 20 inches and 27 inches diameter. It is capable of containing about 8,350,000 gallons, or nearly three days' supply.

Mr. Burnett had maintained that the failures of the service-reservoir were due to the strains set up in the concrete of which it was constructed by the alternations of temperature, and Sir John Fowler, to whom the matter was referred, also assigned this as the cause of the fracture in the walls, and recommended that Mr. Burnett should have charge of the work of repairing them according to the design he gave. Shortly before he left Colombo in the spring of 1890, on a visit to England, Mr. Burnett expressed his intention of communicating to the Institution an account of this work. But it was not to be. In August a letter was received from him saying that he had been laid up almost continuously with malarial fever and must postpone the idea. On the 3rd of November, he wrote again expressing his regret that there was no hope even of his taking part in any of the meetings of the session, and on the 18th of that month he died, having succumbed to repeated attacks of hæmorrhage from the lungs.

Mr. Burnett was well versed in his profession, a good man in the field, quick in calculation, and an excellent designer and draughtsman. His high sense of honour and his natural warm-heartedness made him much beloved by his personal friends, and universally respected by those with whom he was professionally brought in contact.

He was elected a Member of the Institution on the 6th of March, 1877.

PERCY BURRELL was born at Camberwell on the 14th of June, 1833. After passing two years (1849–1851) in the office of his father, the late Mr. John Burrell, Architect, he was articled for four years (1851–1855) to Mr. Thomas Page, with whom he remained for three years after the completion of his articles, as assistant, during the construction of the Windsor, Chelsea, and Westminster Bridges, the Chelsea Embankment, Charrington's Coal Wharf, etc. In January 1859 he entered the service of the Paraguayan Government. In 1862 he and Mr. Valpy

were appointed joint Engineers-in-Chief to the Asuncion and Villa Rica (Government) Railway, and other government works in Paraguay, including topographical military surveys, location and formation of encampments, and the designing and superintendence of important works of defence during the war against Brazil and the Argentine and Uruguayan Republics. At this period about 46 miles of the railway were opened for traffic, and 15 more were ready for rail-laying, and the line as far as Villa Rica was surveyed. Among the works undertaken by the partners were river-improvements, designing machinery, &c., as well as the design and construction of the Palace of President Lopez, which was considerably injured by the allies during the war; but which has now been repaired and adapted for the meetings of Congress, and other State purposes. On the virtual conclusion of the war in the latter part of 1869, Mr. Burrell returned to London, where he and Mr. Valpy were joint engineers to the passing of the Act of the Wharves and Warehouses Steam-Power and Hydraulic-Pressure Company through Parliament, which Act was subsequently taken over by the General Hydraulic Power Company. They were also engaged in bringing out improvements in railway rolling-stock and permanent way for railways and tramways.

After devoting some years to English and foreign professional practice, Mr. Burrell went, in the latter part of 1881, to Venezuela to make a report on the proposed line of railway from the port of La Guaira to Caracas, on which railway he acted as Resident Engineer for Mr. James Livesey from March to November, 1882, when he was compelled to return to England through having suffered a severe sunstroke whilst in the performance of his duties. After a short rest he again resumed practice in London, and in April 1889, became joint engineer with Mr. Valpy to the Paraguay Central Railway.

It is probable that the attack of sunstroke sustained by Mr. Burrell in Venezuela was the cause of his comparatively early death, which took place on the 27th of November, 1890. He was elected a Member of the Institution on the 5th of May, 1874.

JOHN COGHLAN was born of Irish parents in the year 1824, and after a liberal education, was sent at an early age to the "École Central des Arts et Manufactures," in Paris, where he studied

engineer. His first professional essay was under Sir John Macneill and Mr. Charles Vignoles on the surveys of several lines of railway in Ireland. In 1846 he was appointed Assistant-Engineer by the Board of Public Works in Ireland, and was for six years Resident Engineer, during which time he superintended the execution of many public works and improvements. After this he was selected by Sir Charles Fox to proceed to Spain to report upon various projects in which Messrs. Fox and Henderson were engaged. On his return he was specially recommended by Sir Charles Fox and by the Commissioner of Public Works in Ireland, on account of his professional ability and knowledge of foreign languages, to go to Sweden in the service of the Government. There he made the plans and surveys of a railway to unite the ports of Maleño and Helsinborg, and for the creditable manner in which he performed this work he received a highly complimentary letter from the Swedish Government. He was then for nearly three years Engineer in a large engineering establishment in Westphalia, which comprised, among their various undertakings, the construction of railways, the manufacture of locomotives, well-sinking, and other works of utility. It was at this time that the Argentine Republic was beginning to show signs of recovery from the effects of the long civil war, and to devote some attention to works of improvement. Mr. Coghlan, on his return from Prussia in 1857, was selected, through the influence of Mr. Lionel Gisborne, to occupy the position of Government Engineer. From this period commenced the career which made Mr. Coghlan so conspicuous a figure in Argentine affairs, and so valuable in connection with British interests and railway enterprise in that country.

Few men could have entered upon a more important task than that which he undertook, or under circumstances of greater difficulty, where individual character and power were called upon to such an extent; and, on the other hand, few better opportunities could have been offered to any man to distinguish himself, with a young and rising country to work upon, full of life and natural resources, and requiring everything in the shape of scientific appliances to be commenced *ab initio*.

John Coghlan deserves to be described as one of the pioneers of English enterprise on the River Plate. The best testimony to the work performed by Mr. Coghlan, and to the manner in which his services were appreciated by the Argentinos, after thirty years' residence in the country, will be found in a memorial presented

to him on leaving Buenos Ayres in 1887, from which is the following extract:—

"As you are about to return to your native land after an honoured, fruitful and laborious career in the Argentine Republic, we, the undersigned, in bidding you farewell, desire to record our warm recognition of your moral worth, and to give expression to the judgment which the country has formed of those prolonged and valuable services which have contributed so much to its real and solid advancement.

"You came to this country in 1857 as consulting engineer of the Government of Buenos Ayres, and at that early stage of your career you had already earned a high reputation. From that distant period until the day of your departure you may declare with legitimate pride that no important work of public improvement has been carried out in this country without your name being connected with it.

"You prepared a design for the harbour of Buenos Ayres; you carefully explored the River Salado, and proposed to divert into it the water of the Passage with the object of forming a course of interior navigation. You designed docks and warehouses at the Catalinas. You were the co-adjutor of Mr. William Wheelwright in the construction of the Ensenada Railway, and in the negotiations with the Government for the Central Argentine Railway. You constructed the Primer Entreriano Railway. You designed and directed the construction of the water-works at Buenos Ayres. You prepared the design for the drainage of this city, which was the groundwork of the larger scheme of Mr. Bateman. You directed the construction of the great system of Government bridges in the Province of Buenos Ayres. For fourteen years you have, as member and chairman, formed part of the local committee of the Buenos Ayres Great Southern Railway, and you have taken a leading part in the extensions and ramifications of that successful enterprise. For a period of nine years you were the representative in this Republic of the Campana Railway, which under your personal direction has been extended to Rosario and Sunchales. The Central Argentine Railway and the Central Uruguay Railway of Monte Video have from time to time consulted you in connection with the construction of various works. And finally, you have been entrusted on many occasions with important commissions by the National Government of the Republic, and by the Government of the Province of Buenos Ayres, and your opinion and counsel have been solicited by them in every engineering question of importance.

This memorial bears the signatures of the President and Ex-Presidents of the Republic, the British Minister, and all the leading officials and most influential residents in Buenos Ayres.

After a long and honourable career of thirty years Mr. Coghlan returned to his native land, and was elected a Director of the Buenos Ayres Great Southern Railway Company in London in March, 1887. Socially, he was exceedingly hospitable, and made many friends, especially among those who had like himself a cultivated taste for music. He died on the 14th of September, 1890.

Mr. Coghlan was elected a Member of the Institution on the 2nd of May, 1865.

ROBERT JOHN GEORGE was born on the 10th of May, 1841, at Sandgate, Kent. He received his education at Marlborough College and at Frankfort-on-Main, and in May 1858 was articled to the late Mr. John Wright. After a pupilage of three years he became Mr. Wright's chief assistant, and was engaged under him on the surveys of the Rhymney Railway, the Maidstone and Ashford Railway, and the Loose Valley Railway.

In November, 1863, he proceeded to India as a second-class engineer upon the Indus Valley Railway. In April, 1866, he was transferred to the Delhi Railway where he had charge as Resident Engineer of the Jumna Bridge Works, and of a length of line under construction.

In 1870 he returned to England and began practice on his own account. He was employed by the Great Western Railway Company during the conversion of the gauge of the South Wales line in 1872, and in 1873 superintended and arranged for the construction of dock works at Charlestown, Cornwall. In 1874 he was appointed engineer to the new Sewerage Works at Carmarthen, which were designed by him; he also had charge of the waterworks at Fishguard.

In 1883 he came to London, where he was occupied in several commercial transactions, and in 1889 he accepted an appointment under Mr. John Jackson on the Argentine Northern Central Railways Extension. Whilst engaged on this work he died suddenly, on the 19th of August, 1890, at Tuclame through the bursting of a blood-vessel.

Mr. George was elected an Associate-Member of the Institution on the 3rd of May, 1870, and was transferred to the class of Member on the 11th of May, 1875.

THOMAS GRAINGE HURST was born in London on May 2nd, 1824. On the death of his parents he went to the North of England, and was educated there and in Paris. After serving a regular period of pupilage under the late Thomas Atkinson and others, he was engaged for six years, from 1846 to 1852, as Assistant Engineer at Seaton Delaval Colliery under Mr. Thomas Emerson Forster. He was then appointed chief viewer of the Backworth and West Cramlington Collieries, which he continued to manage with great success until the year 1866. During this

period the C Pit was sunk to the Low Main Seam. In 1866 he resigned the viewership at Backworth, and went into North Wales to the Mostyn Colliery. He only remained there a short time, and returning to the North became a partner in the firm of Messrs. T. E. Forster and Co., Mining Engineers, at Newcastle-on-Tyne. At the end of 1873 Mr. Hurst retired from the partnership, and from that time till his death occupied the position of chief viewer to the Seaton Delaval Coal Company, in which firm he was also a partner.

During these years he had charge of the extensive collieries at Seaton Delaval, and also of the sinking and opening out of the New Hartley Colliery. This last was situated close to the Old Hartley Colliery, which was the scene of the lamentable accident of January 1862. The New Hartley shafts were sunk in 1875, and successfully carried down to the Yard Seam, which has since been extensively worked. Feeders were met with near the surface, yielding as much as 1,500 gallons per minute, but they were tubbed back as the sinking proceeded. The drowned workings of the Old Hartley Colliery are separated from New Hartley by a series of faults, and on account of the pressure existing on this drowned area, it was thought prudent by Mr. Hurst to tap the workings and pump the feeders at New Hartley. This was successfully accomplished in 1884, a flow of 800 gallons a minute being placed under control and pumped at the new winning. In 1884 Mr. Hurst sunk the Relief Pit at Seaton Delaval. He had also charge of the Delaval Benwell and Coanwood Collieries for a considerable period.

Mr. Hurst was a Member of the North of England Institute of Mining and Mechanical Engineers from its commencement in 1852, and contributed a valuable paper on the Low Main Seam in Northumberland. He was a Member from the first of the Joint Committee of Masters and Men in the Northumberland Steam-Coal Trade, and always took a great interest in promoting a good feeling between employers and employed.

He had gathered around him Northumberland Miners of the best type, and endeared himself to them by his solicitude for their material and mental improvement. To him the University Extension Movement in the county owed much. The affection with which he was regarded by those in his employ is best evidenced by the following resolution passed at a meeting of the Seaton Delaval Miners shortly after his decease:—

"This meeting of the Seaton Delaval branch of the Northumberland Miners Association begs to condole with the widow and family of the late Mr. Thomas

G. Hurst in their very sad bereavement. The death of a man who combined social qualities of no common order with all the qualities essential to the good management of large collieries is, in the opinion of this meeting, not only a terrible blow to those most closely related to him, but a loss to the coal trade of this district. This meeting would willingly testify that it has long been the boast of the Seaton Delaval workmen that while the management of their collieries was, as regards progressiveness, efficiency and economy, quite a model even among Northumberland collieries, there was not displayed anywhere in the coal trade a greater solicitude on the part of the management for the safety and health of the workmen. Some of the credit due to this state of affairs undoubtedly belongs to the staff of officials who ably supported Mr. Hurst in the management, and who were to a great extent men after his own heart. But in the treatment of his workmen Mr. Hurst was, in the opinion of this meeting, unrivalled by any one occupying a similar position. He gave to his employees that security of employment which enables workmen to perform their work with the greatest efficiency, and which makes it possible for them to cultivate their intellectual and moral faculties. At the same time he carried into practice in the most thoroughgoing manner, the doctrine of the equality of men. He never failed at any time or in any place to recognise his own workmen, and to address to them a kindly word. Though not able at all times to comply with the request of his workmen for higher wages or the redress of grievances, he never failed to meet the workmen's representatives and to discuss with them in the most courteous and thorough manner such matters. He was, in the opinion of this meeting, a great force in favour of industrial conciliation in this county."

Mr. Hurst was a Fellow of the Geological Society. He was elected a Member of the Institution on the 21st of May, 1867. He died on the 21st of July, 1890.

THOMAS JOSEPH was born at Merthyr Tydvil on the 2nd of March, 1819. His education was received at the school of Mr. Taliesin Williams of that town, until at fourteen years of age he left in order to learn colliery management under his father, Mr. Morgan Joseph, who was then manager of the Plymouth Ironworks Collieries, Merthyr Tydvil. Having served his articles, he was entrusted, at the age of eighteen, with the sole management of the clay-ironstone mines, which then supplied all the ironstone used in the eight blast furnaces of these works, and in addition was engaged in the laying of railways in connection with them.

In 1843 he left this place, and in partnership with his brother-in-law, Mr. Samuel Thomas, of Merthyr Tydvil, opened a colliery a few miles below Merthyr, which developed a few years afterwards into a considerable coke-manufacturing works, and is now

being re-started by Mr. S. Thomas's sons, after being unworked for some years.

In 1845, under Mr. I. K. Brunel, he made the surveys, and prepared the parliamentary plans, for the Vale of Neath Railway from Merthyr station to opposite Aberdare, on which there is a tunnel a mile and a half long through the hill which lies between these towns.

Early in 1846 he undertook the management of the coal and clay ironstone mines of the Hirwain Ironworks, then in active operation, belonging to Mr. William Crawshay, of Cyfarthfa.

Towards the end of 1848, in partnership still with Mr. Samuel Thomas, he commenced the Sguborwen Collieries and Ironstone mines, and a few years afterwards the Bwllfa Dare steam coal-pits, both in the Aberdare valley. In 1856 the partnership between him and Mr. Thomas was dissolved, and he soon afterwards opened up for himself collieries on the No. 2 Rhondda bituminous seam in the Rhymney Bargoed and Rhymney valleys, and the Dunraven steam-coal collieries and pits near the head of the Rhondda valley. He also came to be the proprietor of the Blaenclydach colliery in that valley, on the No. 3 Rhondda bituminous seam. These collieries he sold one after the other in the course of years, and most of them, as well as those he won and opened up with Mr. Thomas, have been successful and profitable, and are not yet exhausted. Dunraven has been unsuccessful during the last period of depressed prices, but is now being worked to considerable advantage.

He introduced the edge-rail into use at Danyderi in 1843, instead of the tram-plate, which was before universally employed in the collieries and ironstone mines of South Wales. He contributed several papers to the South Wales Institute of Engineers on mining-subjects, and was much consulted in South Wales on these matters throughout his life; but his own colliery business kept him from following up mining engineering actively as a profession. He was an excellent surveyor and draughtsman, and his knowledge of geology, both general and local, was extensive and accurate.

Mr. Joseph was of a sociable, lovable disposition, and very generous. His eyesight failed very much a few years before his death; but he could see his way about, although he was not able to read. Although suffering from no organic disease, the hard work he had done for many years told upon his constitution. Early in June, 1890, he became ill, and growing weaker and

weaker, passed away on the 10th of July following, in the seventy-second year of his age.

Mr. Joseph was elected a Member of the Institution on the 25th of May, 1880.

SAMUEL KEEFER was born in Thorold, Province of Ontario, Canada, on the 22nd January, 1811. He was of German extraction, his grandfather, George Kieffer, a native of Alsace, born not far from Strasburg, having emigrated about the middle of the last century to America, and settled in the then British Province of New Jersey at Paulinskill, near Newton, the capital of Sussex County. His brother Jacob went on to Pennsylvania, establishing himself near Harrisburg. On the breaking out of the Revolution in 1776, George Kieffer espoused the cause of the House of Hanover, was mustered in the Royalist ranks, and died of army fever upon Staten Island. His son George, born in 1773, was a child at his father's death, and remained at the New Jersey home until his eighteenth year. The family property, consisting of two farms and a distillery, was confiscated by the United States, and George as the son of a "United Empire Loyalist" was offered a home in Canada by the British Government. He followed an Indian trail from New Jersey to the Niagara river at Buffalo, and crossing over, selected a home in Canada about 7 miles from the Falls of Niagara. Returning to New Jersey he brought his mother and brother in 1792 over the same route by packhorses, the men marching on foot. In 1797 he married Catherine Lampman, a German and a Lutheran like himself, and of the five sons and four daughters of this marriage, Samuel Keefer, the subject of this notice, was the fourth son.

George Kieffer spoke German until his arrival in Canada; and here changed the spelling of his name to Keefer, to secure its proper pronunciation by his English neighbours. He served as a Captain in the Canadian Militia in the war of 1812, and was afterwards made a magistrate. When the Welland Canal Company was constituted he became its first President. That great work, commenced in 1824 and completed in 1829, was executed and managed until 1841 by a joint stock company; but upon the union of the Provinces of Upper and Lower Canada, it was taken over by the Government. The canal passed through George

Keefer's property, and for want of any hotel accommodation his house was thrown open to the engineers, and it was through their influence that his son was led to choose the profession of Civil Engineer.

Samuel Keefer's early education was limited to that afforded by the country schools within his reach, but during the construction of the canal, Upper Canada College was founded in Toronto, (then known as York) through the exertions of the Lieutenant-Governor of Upper Canada, Sir John Colborne, afterwards Lord Seaton. Thither, on leaving the Welland Canal, Samuel Keefer went, on March 21st, 1831, and remained until 1833; when, owing probably to his canal experience, he was appointed secretary to the Board of Canal Commissioners for the improvement of the River St. Lawrence. The following year, on the commencement of the construction of the Cornwall Canal, he became assistant to the Chief Engineer, John B. Mills, and continued in this capacity under Mr. Mills' successor, Lieutenant-Colonel Philpot, R.E., until 1839. In that year he was made secretary to the Board of Works then established for Lower Canada by Ordinance of the Special Council, and upon the union of Upper and Lower Canada, which followed the rebellion of 1837; he received the appointment of Engineer to the Board of Works for the United Provinces on 17th August, 1841. Thus at the age of thirty he attained the highest position in his profession in his native country. That this was no sinecure may be inferred from the consideration that at that time, besides the Welland Canal just taken over and needing reconstruction and enlargement, there existed provincial canals upon the St. Lawrence and the Richelieu rivers—while from Gaspe to Lake Huron a main post-road, crossing numerous large rivers, needed to be bridged, turnpiked, and planked or macadamized according as stone or wood was most easily obtainable. Mr. Keefer filled this position from 1841 to 1854, having also in the three years from 1846 to 1848 acted as Chief Engineer to the Welland Canal, in consequence of the resignation of the engineer in charge. In 1852 he made the first surveys for a canal on the Canadian side of the Sault Ste. Marie, the outlet of Lake Superior, which work is now under construction. The works undertaken by the department during the first decade of the union of the Provinces were of the most varied character, consisting of canals, roads, bridges, "slides" for the passage of timber past rapids, harbours and lighthouses. Mr. Keefer personally surveyed and established the line of the Beauharnais canal; the first enlargement of the Lachine canal, and the locks

and dams at St. Anne's on the Ottawa, and at St. Ours on the Richelieu, and directed their construction. In 1850 he substituted for the more costly oak-framed gates previously in use, structures of solid pine for the St. Lawrence Canals, where the locks have a width of 45 to 50 feet. The timbers, shaped like very thick planks, were laid broadside on the top of one another, being reduced at the ends to the width of the heel and toe post, but wider elsewhere so as to be arched against the pressure side, thus giving greater strength, flotation, and durability, as well as economy.

He also constructed in this period, 1843–1844, the first suspension-bridge in Canada, namely, that over the Ottawa river at the Chaudière Falls, which now connects the cities of Ottawa and Hull. A wooden bridge of 300 feet span had been erected upon this site by the Royal Engineers in charge of the Rideau Canal some years previously, but it had fallen soon after its erection. Samuel Keefer had on this occasion an opportunity of utilizing his mathematical knowledge, for which he was distinguished at College. He chose the Fribourg wire, in preference to the Menai chain system, and made his plans with the assistance of the very limited engineering literature then accessible to him—chiefly the 'Engineer and Architect's Journal.' That it is not every engineer who can build a suspension-bridge is evident from subsequent experience in Canada and in the adjoining State of New York. Two Canadian suspension-bridges, one over the Desjardins canal, near Hamilton, Ontario, and the other over the Montmorenci river, near Quebec, were blown away or fell, in the one case with loss of life; while two American bridges, one on the Genesee river at Rochester, and the other over the Niagara river at Queenston, shared the same fate. Mr. Keefer had not even the advantage of his less fortunate successors in having a successful example to refer to. His work served its purpose for forty-five years, and was replaced in 1889, although as serviceable as ever, by a wider steel-truss bridge, which was called for by the increased traffic.

In 1845 he was again called upon to plan an original work of which there was no type in existence. Timber slides for the passage of cribs with men upon them to guide them had been in use for some years, but in order to regulate the depth of water, which must not exceed 12 to 15 inches, stop-logs of varying dimensions were put in or taken out as the river at the head of the slide rose or fell. Mr. Keefer had read in the 'Civil Engineer and Architect's Journal' the account of the bear-trap sluice in use at an early date on the Pennsylvania rivers, but long ago abandoned, and adopted the principle for the construction of an automatic

regulator, so that the gates of the bear-trap, having been set for a given feed of water, would rise or fall with the fluctuation of the stream, and always feed the same quantity. This was applied to the government slides at Ottawa, and worked successfully for years.

In 1853 he resigned his position under the Government for a more lucrative one upon the Grand Trunk Railway, and located the line between Montreal and Kingston, which he had previously surveyed for the Government while in their service. He also conducted the hydrographic survey of the site of the Victoria Bridge, and fixed the line upon which it was constructed, and projected the high-level bridges for this railway over the Ottawa at St. Anne's, and over the Rideau Canal near Kingston. During this period, 1853–1857, he was also Supervising Engineer of the Brockville and Ottawa Railway, a line which connects the St. Lawrence at Brockville with the Ottawa River about 40 miles above the City of Ottawa.

In 1857 he re-entered the Government service, as Inspector of Railways and Deputy Commissioner of Public Works, and for seven years he made a personal inspection of all the Provincial Railways. In the absence of the Chief Commissioner of Public Works, he was entrusted with the selection of the designs for the public buildings at Ottawa. His report on the plans sent in for competition was approved by the Governor in Council in 1859, and the works were commenced under his direction, and were so far advanced that the corner stone was laid by the Prince of Wales in 1860. The arrangement of the detached blocks forming the Parliament Buildings and Departmental Offices upon three sides of a square, is due to him; and no little of the effect of this splendid pile upon a magnificent site is due to this disposition.

He retired from the public service in 1864, but continued to practise his profession, residing at his home in Brockville. In 1869 he undertook the construction of a wire suspension-bridge at Niagara Falls with a span of 1,268 feet, then the longest in existence. An account of this bridge appeared in 'Engineering' in that year.[1] For the plan and details of this work he was awarded a gold medal at the Paris Exhibition of 1878. The bridge stood for nearly twenty years without failure of any kind, but in 1889 the owners, without consulting Mr. Keefer, replaced the single-track roadway by a double-track one, and three months after this new roadway was torn from its cables and guys by a

[1] 'Engineering,' April 23, 30, and May 7, 1869, vol. vii. pp. 268, 285, 300.

terrific wind which registered at Buffalo (18 miles distant) a velocity of 88 miles per hour.

In 1870 he was appointed by the Government Secretary to the Canal Commission, of which Sir Hugh Allan was Chairman. The object of this commission of mercantile men was to determine the scale of navigation for the enlargement of the Canadian Canals. In 1872 he made a survey, plans, and estimates of the Bâie Verte Canal, to connect the Gulf of St. Lawrence and the Bay of Fundy, a project which had been proposed early in the century, but which has now been abandoned in favour of a ship railway over the same route. Colonel Sir Casimir Gzowski, K.C.M.G., was associated with him in this work, which was completed in 1873. In 1875 he built the Dufferin Bridge—a cast-iron arch—over the Rideau Canal in the City of Ottawa, and widened another bridge, a stone arch built by the Royal Engineers over the same canal about fifty years before.

In 1880 he was appointed one of the members of a Royal Commission to enquire into the conduct and prosecution of the Canadian Pacific Railway. Up to that date this railway had been carried on as a public work. A Reform Government had been in power from 1873 to 1878, and had given way to a Conservative one, which was now investigating the work of their predecessors. Samuel Keefer was a pronounced Conservative, and hence the absence of his name in Government connection between 1873 and 1880.

As an experienced constructive engineer, his services as an expert and arbitrator were ever in request. His active participation in these duties continued until 1888, when his final illness began. Deducting the years he spent at college, between his experience on the Welland Canal, as a lad, to his cessation from labour, he must be credited with about sixty years of practice—a long, useful and honourable career, which has in no small degree contributed to the position which Canada holds as the possessor of public works unsurpassed by any country of similar wealth and population. He became a Member of the American Society of Civil Engineers in January 1869, and on the 1st of March of the following year was elected a Member of this Institution. The year before his death he was President of the Canadian Society of Civil Engineers.

In person Mr. Keefer was about the middle height, in disposition he was remarkably cheerful, with an entire freedom from anything approaching irritability. A consistent member of the Church of England, which he represented as a lay delegate both in the Diocesan and Provincial Synods and upon the Mission Board, his

creed was, "Fear God, honour the King, meddle not with them who are given to change." He died at his home in Brockville (from effects of malarial fever contracted nearly two years before in Toronto) on the 9th of January, 1890, within a fortnight of entering upon his eightieth year.

GEORGE NUGENT REYNOLDS LAMBERT was born on the 9th of August, 1836. He received instruction in office work and drawing from Messrs. Leonard and Evans on Inland Navigation Works in Ireland during 1852 and 1853. He then served some years in the Leitrim Militia, where he attained the rank of captain. In 1857 he was employed by Messrs. John Russell and Co. of Walsall and Wednesbury. Between 1862 and 1868 he was engaged under various engineers in surveys on railways and docks in England and Wales, and during this period he laid out and superintended the construction of about 20 miles of the Neath and Brecon and Swansea Vale Railways, from Parliamentary survey to completion.

In 1868 he was sent out by the Secretary of State as 1st Grade Assistant Engineer in the Indian Public Works Department. He arrived in Bombay in the month of November, and was posted to Karachi in Sind. On the 11th January 1869, he was transferred to the neighbouring district of Hyderabad, and there he passed the whole of his service until he was promoted to the important post of Superintending Engineer in Sind on the 24th of March, 1887. He continued to occupy this position up to the date of his death, which took place at Karachi, after a short illness, on the morning of the 13th of August, 1890. On the same date, the Commissioner in Sind published the following:—

"SIND OFFICIAL GAZETTE EXTRAORDINARY."

"The Court in Sind has received, with deep regret, the intelligence of the death of Mr. G. N. R. Lambert, Superintending Engineer in Sind. Mr. Lambert began his service in Sind as Assistant Engineer in December, 1868, and during a period of nearly twenty-two years, devoted himself with unceasing zeal and industry to the development of the resources of the province, and the improvement of the condition of the people. In him the State has lost a valuable servant, and the people of the province a true and trusted friend."

Those who were personally acquainted with George Lambert testify to the fidelity of the above description of him, as a servant of the State and as a friend of the people. When, in 1887, he

was promoted to be the head of the department in which he had so long, so faithfully, and so ably served, all who knew him intimately felt that he was the right man in the right place.

The cultivated portion of Sind is covered with a network of inundation canals, and on their proper management depends the entire land revenue of the Province. All draw their supply from the River Indus, the irregularities in the flow of which are such as to defy the most careful calculations. But George Lambert, from long experience and close observation, had so mastered the intricacies of the canal system in Sind, that he never allowed himself to be taken by surprise. He seemed to know by intuition what was likely to happen, and to be prepared for every emergency.

It would take long to describe all that he did for the good of the State and the welfare of the people during the fifteen or sixteen years that he held executive charge of a canal division. By his canal administration he largely increased the Government revenue, and materially added to the prosperity of the people. His few faults and his many virtues were those of a warm-hearted Irishman. With no book knowledge of the Sindhi language, and with singular inability to cope with its colloquial difficulties, he yet understood with wonderful quickness what any Zemindar (landowner) wanted of his Department, and, somehow or other, contrived to make himself understood in his turn. He was very accessible to the people, and would ride miles out of his way to visit the lands of the poorest Zemindar who complained of insufficient water-supply, and thought he could point out a way of increasing it.

George Lambert was only 54 years of age, and when, less than a year ago, he came to England on short leave, his friends all thought he had still many years in which to work. At the time of his death, he held the rank of Major in the Sind Volunteer Rifle Corps, and he was therefore interred at Karachi with military honours. Probably few of those who stood around his grave were aware that they were thus paying the last tribute of respect to one of "Garibaldi's Englishmen."

Mr. Lambert was elected a Member of the Institution on the 6th of December, 1881.

CHARLES EDWARD WALKER OGILVIE was born at Orchard Head, Bothkennar, near Falkirk, on the 23rd of October, 1823, and was educated at St. Peter's Collegiate School, Eaton Square, London, under Dr. Wilson.

After serving articles under Mr. Lomax he became assistant to Mr. George Hennet, under whom he had his first experience of railway work, being engaged in constructing portions of the Bristol and Gloucester, the Cheltenham and Great Western Union, and the South Devon Railways. From 1853 to 1858 he was Assistant Engineer to the late Mr. Brunel, and acted under Mr. Margary, in maintaining the South Devon Railway.

In June, 1858, Mr. Ogilvie was appointed District Engineer on the Loop line of the Great Northern Railway at Boston, and in July 1861 was transferred to a similar position on the northern district of the same railway, extending from Peterborough to Shaftholme Junction, a length of 85 miles, and including the branch from Grantham to Nottingham of 23 miles, and that from Grantham to Lincoln 17 miles, besides 50 miles of the Grantham and Nottingham Canals, between Grantham and Langley Mill, making a total of 175 miles of works under his superintendence and direction. This position he held for the long period of more than twenty-nine years until his death.

Mr. Ogilvie's health failed in the early part of 1890, and after a long and painful illness he died on the 29th of August following. He was elected an Associate Member of the Institution on the 6th of May, 1862, and was transferred to the class of Member on the 29th of January, 1878.

JAMES OLDHAM was born in Hull on the 23rd of June, 1801. He was the son of a millwright, and showed at an early age a strong taste for drawing and mechanical pursuits. At the age of fourteen, however, in consequence of a somewhat hasty decision, he went to sea and spent two years in voyages to the Baltic. Mr. Oldham was fond of relating in after years that he was afloat on the North Sea when the Battle of Waterloo was fought. The hardships of a seafaring life proving too much for his strength he returned, and after some time spent with an uncle in Lincolnshire to regain his health, he was apprenticed to his father as a millwright or mechanical engineer. His ability and enterprise soon became manifest. He was quite a young man when the Hull Corporation invited engineers to send in drawings and estimates for building a movable bridge (the predecessor of the present North Bridge), and though there were older and more

experienced men in the field, Mr. Oldham was successful in the competition, and was ordered to build the bridge.

From this time he practised chiefly as a civil engineer, and soon gained a good connection, being appointed surveyor for some of the principal highways in the Hull district, while he also held the post of Government Inspector of Steamships. It is interesting to note that on the 31st of August, 1840, Mr. Oldham was appointed "Sole Agent for the disposal of Licenses to use Smith's Patent Screw Propeller for the Town of Hull and River Humber." He acted as engineer to several bodies of Drainage Commissioners in Holderness, and carried out the Keyingham, Sunk Island, and Winestead Cloughs. In 1844 he was Engineer for a projected line of railway from New Holland to Gainsborough, and in 1845 he was one of the Engineers for the then proposed Hull and Barnsley Junction Railway. In 1850 Mr. Oldham was employed by Her Majesty's Commissioner of Woods and Forests to reclaim what is now the eastern portion of Sunk Island, a tract of about 700 acres, in the estuary of the Humber. This land is somewhat below the level of high-water, and is preserved from inundation by a system of dykes and sluices. In 1852–3 Mr. Oldham was instructed to make surveys for the reclamation of a much larger portion of the estuary extending from Sunk Island to Spurn Point, including from 2,000 to 3,000 acres. This project was abandoned for the time owing to the breaking out of the war with Russia, but recently Mr. Oldham's partner, Mr. Bohn, has received instructions from the Government to report upon the possibility of reclaiming a tract of between 500 and 1,000 acres adjoining that already dealt with.

Mr. Oldham constructed several bridges in Holderness, and in 1867 and 1868 he made a survey with reference to the land above tidal influence. He was the Government Inspector of Steamers for the Port of Hull for many years, and his knowledge of seafaring life proved of value to him in fulfilling the duties of this post. He also acted as Surveyor of the Garrison Ground until the office became extinct through the absorption of the land by the ever-growing docks of the town.

Mr. Oldham's knowledge of Hull and its neighbourhood, especially of the River Humber, led to his being consulted constantly by owners of property and promoters of new enterprises in the borough or the country around, and there was hardly a scheme proposed, whether railway, docks, or water-supply, or any public work of utility, in which Mr. Oldham was not one of the witnesses summoned to give evidence before Committees of both Houses of

Parliament. Many encomiums were passed upon him on these occasions. His evidence was always concise and to the point, and given in a clear voice. He was keenly interested in the intellectual progress of the people, and for years was an active advocate and supporter of Mechanics' and Literary Institutes, frequently lecturing for them in Hull and elsewhere. He was a member of the Hull Literary and Philosophical Society, and read a Paper in 1858 on the "Supply of Water for Domestic and other Purposes," and in 1860 on the "North Atlantic Telegraph." When the British Association for the Advancement of Science held its meeting in Hull in 1853, Mr. Oldham became a member, and read a Paper on "The Rise and Progress of Steam Navigation in Hull," and one on "The Physical Features of the Humber," both of which were published *in extenso* in its Report. At the meeting at Leeds, in 1858, he presented a Paper on the "Gresham Buoy" for recording the loss of ships at sea, and in 1861 in Manchester one on the "Port of Hull." In 1862 he communicated to The Institution of Civil Engineers a Paper on the "Reclamation of Land from Seas and Estuaries," for which he was awarded a Council Premium. This Paper dealt chiefly with the land reclaimed from the Humber. Mr. Oldham considered that Hull possessed greater advantages than any other port in the British Isles, being situated on an estuary, which is the outlet of the drainage of about one-fifth of the surface of England, and is not solely dependent on tidal action, and there being no bar or obstruction at the entrance of the river, so that the largest ships afloat could enter and run up to the port at dead low-water.

From 1862 to 1864 he superintended an important series of tidal observations on the Humber, Trent, and Ouse, grants of money having been made for that purpose by the British Association. Reports were presented to the meeting at Cambridge, and subsequently together with the results of a series of borings made in the bed of the river.

In 1874 Mr. George Bohn became a partner with Mr. Oldham. This connection was a source of comfort and satisfaction to the older man; he highly appreciated the qualifications of his junior, whilst Mr. Bohn gives testimony to the kindness and amiability of his partner, and has often said that there was never a disagreement between them. The scheme for the Hull and Barnsley Railway was revived, the Bill obtained, and the railway constructed, with the addition of the Alexandra Dock. In the carrying out of these works, Mr. Bohn had a large share, Mr. Oldham taking great interest in the progress of them,

In all the social relationships of life Mr. Oldham was highly esteemed. He was kind and genial, and won the respect of those who worked with him or for him. He had a fund of information and *bonhomie*, which enabled him easily to take his proper place in any society, but it was in the domestic circle that his loyal character was best shown. Upright in person, he was also upright in mind and heart, generous and kind to all. Congestion of the lungs in March 1889, followed by a gradual decline of strength, terminated a long and useful life on June 10th, 1890. All who knew him agree that he combined in a singularly happy way the character of the man of business and of science with that of the gentleman and the sincere Christian.

Mr. Oldham was elected a Member on the 28th of January, 1834, being at his death the Father of the Institution.

THOMAS COLCLOUGH WATSON, eldest son of Mr. William Jonas Watson, of the Manor House, St. Nicholas, Glamorgan, was born on the 29th of August, 1822. He was a pupil of Mr. George Turnbull during the construction of the West Bute Dock, at Cardiff, and was also employed on the Middlesbro' Docks. He was next engaged with Mr. P. Barlow upon railway work at Tunbridge, and in 1847 upon the railway from Louvain to the Sambre in Belgium, after which he was for some time Resident Engineer on the Great Northern Railway, at Grantham. He spent eight years at Örebro, on the Royal Swedish Railway, and his services on that line, the first railway constructed in Sweden, were highly appreciated by the king, who offered him a decoration. He also made a private railway there for Mr. Oscar Dickson.

After successfully completing his work in Sweden, he went to Russia as Chief Resident Engineer on the Riga and Dünaburg Railway, under Sir John Hawkshaw, and subsequently became the contractor for the completion of the works, in partnership with Mr. James Ashbury. It was during this latter period that the accident happened by which he lost his right leg. The train by which he was travelling in his carriage was wrecked by running over a trolly that some workmen had left on the line,

about 40 miles from Riga. His servant, sitting on the box, was killed.

In 1864, Mr. Watson went to Holland, and while there superintended, on behalf of Messrs. H. Lee and Sons, the construction of the Zuider Zee locks, and the closing of the Y, an estuary of the Zuider Zee, east of Amsterdam, by means of fascines, and afterwards took charge of the works between Amsterdam and the North Sea harbour. A description of this method of forming dams, so extensively used in Holland, was communicated by him to the Institution.[1] For this essay Mr. Watson received a Telford Premium. Since that time he had been engaged upon railways at Natal, and on the La Guaira and Caraccas Railway.

Mr. Watson died suddenly on the 2nd of July, 1890, on board his yacht the "Kriemhilda." He had been cruising in the Channel for about a fortnight, and had put into Ryde, before proceeding to Dartmouth, and thence to the Forth Bridge. He had gone on deck, feeling in excellent health, to smoke a cigar, as was his custom after breakfast, and was thought to be sleeping in his chair. After a while some matter arising as to which it was necessary to consult him, it was found that he had passed away without a struggle, and without any of those who were near his chair being aware that anything was wrong with him. The cause of his death was apoplexy.

Mr. Watson was of a most kind and genial disposition, generous to a fault, and ever ready to help his friends, especially those in distress, and was universally beloved and respected. He was elected a Member of the Institution on the 6th of March, 1849.

THOMAS PLANTAGENET BIGG-WITHER was the tenth son of Lovelace Bigg-Wither, of Manydown and Tangier Parks, in Hampshire, where the family had resided for more than five hundred years. Thomas was born at Tangier Park on the 8th of October, 1845. He was educated at Bradfield College, Berkshire, and at King's College, London, where, in 1865, he entered the Applied Science Department. He showed considerable natural ability, gaining several prizes, and his success decided him to

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[1] Minutes of Proceedings Inst. C.E., vol. xli. p. 158.

the same determination of character and enthusiasm in overcoming obstacles with which it was begun.

He entered as a pupil upon the Admiralty Dockyard Extension Works at Portsmouth, the most extensive engineering operations of the kind at that time, and laboured hard to acquire a thorough practical knowledge of his profession. It was during this period that he gained a Whitworth Exhibition, and afterwards competed for a Whitworth Scholarship, which he missed only by a few points. He was still anxious to obtain further insight into the work, but under conditions of responsibility which the position of a pupil did not carry. This he could only do (under the somewhat antiquated rules of the service) by becoming a paid member of the outdoor staff, as a Foreman of Works, in which capacity he had charge of a section of the work for some time, carrying out his duties in a manner which gave the greatest satisfaction in every way.

In 1872 he was attached to an expedition sanctioned by the Emperor of Brazil, under the direction of Captain Palm, a Swedish engineer, to explore and survey for a proposed railway from Curitiba in the province of Parana, to Miranda in the interior province of Matto Grosso, Brazil. One of the divisions of the expedition to which he was Assistant Engineer was allotted a section of the work in the valley of the River Ivahy, a large tributary of the River Parana; and for nearly two years he faced the hardships, difficulties, and perils only known to those who have had similar experiences in the virgin forests and almost unexplored and uninhabited regions of South America. He threw himself heartily into the undertaking, but his staff was destined to much misfortune; some of its members became incapacitated by ill health, and a large share of the work fell upon his shoulders. He himself more than once nearly lost his life from exposure and privation in the forests, and misadventure in passing the dangerous cataracts of the river, which was the principal means of communication both for the purposes of the survey and for obtaining supplies. But the most arduous part of the work was completed before a further break-up of his staff occurred, and the remainder of the section was finished by other members of the expedition, who were by that time free to undertake it, while Mr. Bigg-Wither was chosen to conduct the exploration of an alternative route in the valley of the River Tibagy. Upon the satisfactory completion of his work he returned to England in 1875. He read a Paper before the Royal Geographical Society, in June 1876, descriptive

of the Tibagy valley, and subsequently published a spirited and interesting book entitled "Pioneering in South Brazil," in which he gave an account of his varied experiences and adventures.

He remained in England until 1882, taking pupils in surveying and engineering, when he entered the service of the Bengal Central Railway Company. In March 1883 he was appointed an Assistant Engineer to the Bengal and North-Western Railway Companies, and in this capacity constructed 20 miles of the Gonda Division. In September 1884 he was transferred to Gorakhpur, the head-quarters of the railway, as Resident Engineer, and from April 1887 until the time of his death was Resident Engineer of the whole line, responsible for its maintenance, and having charge of new branches under construction. He worked with untiring zeal and energy, and took the greatest interest in his work, allowing nothing to interfere with his duties; but in the exhausting climate of the plains of India his already overtaxed strength broke down under the extra strain of the illness of one of his family. He was ordered home, but sank from exhaustion on board the P. & O. steamship "Assam," and his body was committed to the deep a few hours before reaching Aden, on the 19th of July, 1890.

He was elected an Associate of the Institution on the 14th of May, 1872, and was one of those transferred to the class of Associate Members by the Council in 1878.

GEORGE WADHAM FLOYER was born on the 19th of November, 1863, at Marsh Chapel, near Grimsby, Lincolnshire, of which place his father, the Rev. Ayscoghe Floyer, was rector.

From 1873 to 1874 he was a chorister at the Chapel Royal, St. James's, and received his education as such. From 1874 to 1878 he was at St. Mark's School, Windsor, under the late Rev. Stephen Hawtrey. In 1879 he became a Student of the Crystal Palace Company's School of Engineering, where he gained certificates and much credit for his accuracy in drawing and calculations. In 1882 he was sent as a pupil to Mr. John Newton on the Whitby, Redcar and Middlesburgh Union Railway, but his time there was shortened to about eleven weeks by the offer of an appointment as draughtsman in the office of Messrs. Cutbill, Son, and De Lungo, in which capacity his accuracy and ability for mathematics again served him well. In August, 1883, he was appointed by them Assistant-Engineer on the extension of the

Jersey Railway from St. Aubyn to La Moye. From November, 1884, to August, 1886, he was again in London in the office of the firm. In 1886 he was sent out by them as District-Engineer on the portion of the Brazil Great Southern Railway from Uruguayana to Itaqui.

This region, though near enough to the Argentine Republic to have a less unhealthy climate than the more northern portions of Brazil, was yet so uncivilized as to necessitate Mr. Floyer's leading an extremely rough life, and the scarcity of suitable food and other privations combined to weaken a constitution which was never strong. In April, 1888, he returned to England, and later in the same year he was appointed Assistant-Engineer by the Ceylon Government on the Haputah Extension Railway. In November, 1889, he resigned his appointment mainly on account of ill-health, and went to visit relations in Egypt.

In April, 1890, he received an appointment from the Egyptian Government as Engineer in Charge of the construction of the 90 miles of railway from Assiout to Girgeh, this being an extension of the government railway from Cairo to Assiout. He had been working at high pressure to finish as much work as possible before the rising of the Nile put a stop to the work, and though he succeeded in his object, the strain was too much for him. On the 28th of August he broke a blood-vessel, and on the following day closed an exceedingly promising career at the age of 26.

Mr. Floyer was of an energetic and somewhat restless disposition, careful that his work should be done well, and inclined to be intolerant of carelessness or mismanagement. His unfailing good nature and generosity made him popular with all who knew him. He was elected an Associate-Member of the Institution on the 4th of December, 1888, having previously been a Student.

CONRAD HENRY WALTER GRUNDTVIG, the eldest son of the late Frederick H. T. Grundtvig, was born at Rio de Janeiro, on the 6th February, 1861. At the age of eight he came to England for his education, and at sixteen he was entered as a student at Collège Rollin, Paris, where he remained nearly two years. He received practical training in the workshops of Messrs. Manlove, Alliott, Fryer and Company of Nottingham, from 1879 until 1880. He then served as a pupil in the office of Messrs. Law and Chatterton for four years, and was engaged on the Devonport and Stonehouse Main Drainage, and other works. On the

completion of his pupilage he was employed by Messrs. Law and Chatterton as an assistant for three years, during which time he acted as Resident Engineer for the Allington Lock on the River Medway, and for the West Malling Main Sewerage Works. In March 1888 Mr. Grundtvig was appointed Assistant Engineer on the works of the Lake Copäis Reclamation Company. The duties of this position were of a most arduous and responsible nature, and he remained at Lake Copäis until the day of his death, with the exception of one brief visit to England in 1889.

The circumstances relating to his death are extremely sad. The lake is now practically dry, but is still covered with reeds from 9 to 20 feet in height. On the 22nd of August, 1890, Mr. Grundtvig was engaged in setting out the bed of it into kilometre squares. As there was no clear space of sufficient length to use as a base line, he decided to cut a line due north and south, right through the lake. This had been nearly completed, and Mr. Grundtvig went into the cutting with a theodolite to range a line for the men to continue working by, but after going in about two kilometres he found that he could not see on account of smoke, and the ground was so hot from a recent fire that his men with their light native shoes were unable to remain there; he therefore went on to see the workmen at the end of the line (about 12 kilometres from his house, from which he had started at 3 o'clock in the morning) and reached them at about 11 o'clock. Tasso Andreas, the leading man, advised Mr. Grundtvig to have something to eat and rest for a few hours, as he thought it would be impossible for him at that time to make his way through the smoke. Mr. Grundtvig, however, would not be persuaded to rest, but went on with his work and then started homewards. When Tasso and his men reached a point about 2 kilometres from the commencement of the line, they heard a shouting from the midst of the reeds, and on going to see what it was, found the two men who had been with Mr. Grundtvig. Their account was that after arriving at the place where they had given up work in the morning, they found that a fresh fire had broken out; so, being unable to proceed, and thoroughly exhausted, having had no food since 3 o'clock in the morning, they all three (Mr. Grundtvig and the two workmen) walked about 50 yards into the reeds, and scraped a hole to get water, after which they went to sleep. The workmen, waking up, found Mr. Grundtvig gone, and expecting that he had tried to push his way through the reeds to the canal, about 1,400 yards distant, went to look for him there, but could find no trace of him. It was now dusk and their eyes were very bad with smoke. As Mr. Grundtvig had not been seen by any one,

At 4 A.M. on the following day over one hundred men commenced to explore the reeds, and eventually his body was found close to the place where the workmen had rested. He was half sitting and half lying down, in a perfectly natural position, with his theodolite in his hand. The supposition is that, after leaving the two workmen, he endeavoured to make his way to Moulki (his home), but being encountered by one of the fresh fires, he hastily retraced his steps, and, feeling exhausted, sat down to rest and was asphyxiated by the fumes of the burning reeds while he slept. This view was confirmed by the medical evidence.

His body was brought to Athens on Sunday morning the 24th of August, and buried in the presence of Mr. W. H. Haggard, Chargé d'Affaires, and the Members of the British Legation, with other English residents, the funeral service being read by the Chaplain of H.M.S. "Dreadnought." A tablet to his memory is being erected in the English Church at Athens, by the Lake Copäis Company, while his local friends have intimated their intention of erecting a memorial on the spot where he died.

Mr. Grundtvig was a young engineer of brilliant talents, and very fond of his profession; and those who knew him testify to the earnest and thoroughly business-like way in which he carried out all his work. He was a good photographer, and an excellent linguist. He had learned to speak Greek fluently, and at the time of his death had nearly mastered the Albanian language. Mr. Grundtvig was a lieutenant in the 1st Middlesex Engineer Volunteers, and had passed every examination open to Engineer Volunteers. He became a Student of the Institution on the 10th of February, 1880, and was elected an Associate Member on the 7th of December, 1886.

WILLIAM VYE PADDON was born on the 10th of July, 1859. In 1876 he was articled to his father, Mr. John Birch Paddon, who employed him after the completion of his articles in the design and supervision of works for the Brighton and Hove, the Southampton, and other Gas Companies.

In 1881 he went to Natal, and became Assistant to Mr. E. A. R. Innis, and in 1883 was appointed Assistant and Resident Engineer for the construction of the south breakwater of the Port Natal

Harbour Works. Mr. Paddon was frequently in sole charge of the works at Durban, and satisfactorily contributed to their successful completion.

Having given special attention to the subject of Military Engineering, he obtained, in 1885, a commission in the Egyptian Army under General Sir Charles Baker, as Technical Officer with the rank of captain. In this position he received many marks of distinction, and was often complimented by his superior officers for the successful performance of difficult duties. He died while on sick-leave, at the residence of his father, near Neath, on the 9th of July, 1890.

Mr. Paddon was admitted a Student of the Institution, in 1877, and was elected Associate-Member on the 2nd of December, 1884.

WILLIAM HAYWARD was born on the 10th of January, 1841. When about eighteen years of age he entered the service of the Thames Ironworks and Shipbuilding Company, being employed at first as a draughtsman. After a time he became assistant-secretary, then secretary, and finally manager, earning continually the confidence of those to whom he was responsible and the esteem of all who knew him. Possessed of exceptional financial abilities, unswerving integrity and sound judgment, he was able, in the face of a competition from centres where labour, material, and coal are cheaper, to maintain the reputation of London shipbuilding. He was responsible for the building of H.M.SS. "Benbow," "Sans Pareil," "Blenheim," "Grafton," and "Theseus," besides smaller craft for the British navy and for foreign governments, and the ironwork of the Blackfriars Bridge and of the Barry Docks was constructed under his management. During the thirty-two years that he served the Company many opportunities arose, in times of depression and strikes as well as in prosperous and busy seasons, when his energy and tact were conspicuously manifest, and his loss will be felt not only by the Company, but by those with whom he had worked, and to whom he had endeared himself as a personal friend.

Mr. Hayward was elected an Associate of the Institution on the 2nd of April, 1878. He died on the 20th of September, 1890, of anæmia.

MAJOR-GENERAL CHARLES PASLEY, C.B., late Royal Engineers, was the eldest and last surviving son of Lieutenant-General Sir Charles Pasley, K.C.B., R.E.[1] He was born at Chatham, where his father was at that time Director of the Royal Engineer Establishment, on the 14th November, 1824. In 1834 he entered Mr. Whiston's school at Rochester, and it is related that whilst on a visit to London, in the summer of that year, he rode out every morning, "first studying the map and arranging his course." The love of topography, which manifested itself thus early, lasted throughout his life, and one of his conspicuous characteristics was intense observation and interest in the study of locality. He was of a studious disposition, and during his holidays applied himself to the study of decimals and algebra in his father's office in Brompton Barracks, Chatham.

After passing through the Royal Military Academy at Woolwich, he received, in 1843, his commission in the Royal Engineers, and two years later filled a temporary vacancy in the Office of Instruction in surveying and astronomy at the Royal Engineer Establishment. In 1846 he went to Canada, where he remained for three years, during the first two of which he lived, most of the time, in a beautifully situated old house on the Island of St. Helen's, opposite Montreal, which had formerly belonged to the Canadian Barons de Longueuil, and was even then known by the name of the "Barony House." In the autumn of 1848 he was stationed at Bytown (now Ottawa), and appointed to assist a brother officer in the survey of the very extensive but scattered estates belonging to the Board of Ordnance on the Rideau Canal. They did the survey work in winter to avoid mosquitoes, swamps, and malaria, and to enable them to chain across the frozen rivers, leaving the necessary office work to be done during the summer months. In 1850 he was employed by the Colonial Government at Bermuda in deepening and improving the entrance to St. George's Harbour.

In 1851 he was ordered to do duty at the Great Exhibition with many other Royal Engineer officers. He was superintendent of classes 24 and 25 (glass and china), with an office in the building, and after the opening had a still larger area under his superintendence.

In 1853 Lieutenant Pasley received his appointment as Colonial

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[1] An obituary notice of Sir Charles Pasley appeared in the Minutes of Proceedings, vol. xxi.

Engineer to the Colony of Victoria, and on arriving in Melbourne, in September of that year, he found himself at the head of a large department, with the additional duties, after a short time, of Colonial Architect, and subsequently those of the Central Road Board. In 1854 he was made member of a commission to make arrangements for an exhibition of colonial products at the Paris Exhibition in the following year. Six months later he was nominated to a seat in the Legislative Council of Victoria. One month after this the Ballarat riots broke out, and he offered his services to the Governor (Sir Charles Hotham), and was sent to the Ballarat Gold Fields, where he assisted in the capture of a stockade occupied by the insurgents, on the 3rd of December, 1854. In 1855 a new constitution came into force in Victoria, and a responsible ministry was formed, he being one of the members. Upon this taking place he was formally appointed Commissioner of Public Works. On December 10th he was appointed a member of the Executive Council, and a few months later was made by an Act of Council a joint trustee with Captain (now Lieutenant-General Sir Andrew) Clarke, R.E., for the Melbourne and Mount Alexander railway purchased by Government.

In 1856 Captain Pasley was elected Member for South Bourke. The Houses of Parliament were among the public buildings erected under his directions, and some of the principal streets of Melbourne were laid out during his term of office. The last public building with which he was connected was the Melbourne Post Office; but this was not completed until after his return to England. He also took the greatest interest in the Botanic Gardens, the herbarium of which was built under his auspices, and the Curator, Baron von Mueller, who still remains there, and is well known as a botanist, received his appointment at this time. In 1860 he resigned the office of Commissioner of Public Works with the intention of returning to England, but his interest in the welfare of the Colony of Victoria and of the City of Melbourne was as keen as ever in after years. Before his departure from the Colony the New Zealand War broke out, and he immediately offered his services, which were accepted the same day, and he was appointed an extra member of Major-General (afterwards Sir Thomas) Pratt's staff. Three months later he was severely wounded by a bullet in the thigh while in charge of trenches, after laying out and constructing a parallel used in the capture of the Kaihihi Pah. His wound proved so serious that he became unfit for further duty, and returned to Melbourne

Murphy, speaker of the House of Assembly, on behalf of the Colony. A friend and colleague of his during these years now writes:—" I had known him for above thirty-five years, since the time when he first became member of the Government of Victoria. His colleagues were greatly impressed by him from the first. His industry and extreme accuracy were extraordinary, and we of the first cabinet at Melbourne felt always safe if he undertook any difficult business, whether in his office or in the House. His department was by no means a bed of roses. But he did his work to the satisfaction of everybody, including the hostile critics of the opposition. The same was the case when he took over for a time the Victorian Agency. It is not given to everybody to be both shrewd in the conduct of affairs and also blameless; to live a long life without censure, but at the same time to be efficient in dangerous and difficult times. But this was essentially General Pasley's character, and he was appreciated accordingly."

For his services in the New Zealand War he was mentioned in despatches and promoted to Brevet-Major, he having become Captain soon after his arrival in Melbourne. In 1861 he returned to England still very lame from his wound, and received the sad news of his father's death on his arrival. The same year he was made Commanding Royal Engineer at Gravesend, and read a paper on the New Zealand War at two meetings of the Royal United Service Institution.

In 1864 he was made Acting Agent-General for the Colony of Victoria, a temporary appointment which he held for four years, with leave from the War Office, and afterwards from the Admiralty, to accommodate the Colony until they were able to make a permanent appointment. During this time he superintended, on behalf of the Colony, the equipment of the ironclad "Nelson," and the design, construction, armament, and despatch of the "Cerberus" turret-ship, both ships being sent out to the Colony to assist in the defence of Melbourne Harbour. It may be here noted that, at the request of the Colony, he again served as Acting Agent-General for Victoria from 1880 to 1882.

In July, 1865, Major Pasley left Gravesend, and became Superintending Engineer at Chatham Dockyard, where an immense extension of docks and basins had been planned, and was carried out under his superintendence, and upon completion added to the old yard.

In December, 1870, Colonel Pasley was appointed by Mr.

Childers (First Lord of the Admiralty) Honorary Secretary of the Committee on Designs for Ships of War, and soon after was made a member of the Committee as well as Honorary Secretary. Lord Dufferin was the Chairman. This work occupied many months in the following year, and on its conclusion Colonel Pasley was thanked both officially and privately for his services, and especially for the drawing-up of the report.

In the autumn of 1873 he succeeded Sir Andrew Clarke, R.E., as Director of Works to the Admiralty, and thenceforward had the control of all the works at the naval establishments at home and abroad, and of the coast-guard stations throughout the country.

The more important works designed in his office at the Admiralty under his supervision were: the entrance locks at Chatham yard, with their ingenious sliding caissons; the two first-class dry docks at Devonport and Haulbowline, which have novel arrangements for lessening the length of the cumbrous timbers usually employed for shoring vessels. The naval barracks at Keyham; the College for Naval Engineers, Keyham; the completion of the alteration of Greenwich Hospital to a naval college, with the elegant block of buildings for racket and fives courts.

The extensions of Chatham, Portsmouth, and Haulbowline dockyards were carried on during General Pasley's term of office. Minor works were the dining hall and swimming bath at Greenwich Hospital School, various buildings at Plymouth Marine Barracks and at Walmer Marine Barracks; church at the Royal Naval Hospital, Plymouth; the Admiralty House at Queenstown; the infirmary at the Royal Marine Artillery Barracks, Eastney; the iron-ship-repairing shop, Malta dockyard, with numerous coast-guard stations, while many other works at the naval establishments were carried out under his less direct supervision.

During his term of office at the Admiralty, General Pasley was also member of a Commission on the proposed improvement of Alexandria Harbour, and member of the Committee of 1882 on the employment of convicts, which resulted in the construction of the new Harbour of Refuge at Peterhead. He attained the rank of Colonel in the Corps of Royal Engineers, April 1st, 1876, and retired with the rank of Major-General on August 27th, 1881.

In recognition of his valuable services under the Admiralty, Major-General Pasley was created a Civil Companion of the Bath on April 23rd, 1880. He retired from the post of Director of Works in 1882.

He was very fond of music, and his love of books began at an early age, when he spent all his pocket-money in the acquisition of them. He had a very retentive and accurate memory, and to exemplify the service which this proved to his friends as well as to himself, it may be mentioned that while on a visit to the Mediterranean with the Lords of the Admiralty, soon after the acquisition of the Island of Cyprus, at an entertainment in Toulon Harbour, sitting next a French admiral, he discussed the peculiarities of the harbour, which he then visited for the first time; and on the French admiral begging to know whence he had obtained such particular information, Major-General Pasley promised him extracts from books at home—a promise which he afterwards fulfilled. He had been ill with increasing weakness for over five years, and died rather suddenly on November 11th, 1890. He was elected Associate of the Institution on the 10th of April, 1866.

WILLIAM MARSTON WARDEN, the eldest son of the late Mr. Joseph Warden, was born at Birmingham on the 1st of May, 1815. He was educated at a private school, and at an early age joined his father in the business still known as Messrs. Joseph Warden and Sons, Railway Iron-works, Birmingham, and of which, from his untiring energy and business capacity, he soon became the leading spirit. Later, he joined the Oak Farm and the Whittington Iron-works, and in 1857 established the Phœnix Bolt and Nut Works, now located at Handsworth, near Birmingham. He was also a partner in the firm of Messrs. Warden, Clark and Muirhead, electrical engineers and contractors, and during his connection with them many important undertakings were executed, including the telegraph from King William's Town to Queenstown and Beaufort West, some 1,200 miles into the interior of Southern Africa, at that time but little explored.

In the early days of railway development, wherever extensive works were being carried out, Mr. Warden was constantly to be seen, a favourite alike with engineers and contractors, among whom Messrs. Brassey, Wythes, Betts, Walker and many other eminent railway pioneers were his personal friends. From Mr. Warden's wide experience and sound judgment, his advice in commercial and financial matters was much sought after, and for some years he was Director and Chairman of the Birmingham Banking Company, the Birmingham Waterworks Company, the

Alliance Assurance and many other important companies. He was also a Justice of the Peace for the county of Stafford, sitting regularly on the Bench, until unable to attend through failing health.

Movements of a philanthropic character ever found in him a generous supporter, and for a long course of years he was a willing subscriber to most of the charitable institutions of Birmingham and the neighbourhood. Hospitality and kindness of heart were the prominent features of his character, and although not taking an active part in public life, either politically or otherwise, he was always ready to lend a helping hand in promoting institutions for the benefit of the poor and needy, and in an unostentatious way he exercised much generosity. He possessed artistic tastes of no mean order, and has left a fine collection of paintings by leading artists. He was also a keen sportsman, yearly looking forward to the 1st of September, and until within a few years of his death was fond of horse exercise.

Mr. Warden died at his residence, Fairlawn, Edgbaston, on the 16th November, 1890, from a painful disease of which he had been a sufferer for some considerable time. He was elected an Associate of the Institution on the 3rd of March, 1863.

WILLIAM HERON STEEL. Since the Obituary notice appeared in Vol. C, Session 1889–90, Part II, some additional information has come to hand relative to his professional career in the Colony of Victoria.

It appears that Mr. Steel entered the Public Works Office of the Colony in Melbourne in a comparatively subordinate capacity; but he there displayed such marked ability, that the head of the Department, Mr. W. Wardell, Chief Inspector, soon caused him to be promoted, and to be entrusted with much more important work than had previously been committed to his charge. At Mr. Wardell's instance, Mr. Steel was before long appointed that gentleman's Chief Assistant, and so remained until he succeeded to the office of Inspector-General.

*** The following deaths, in addition to some of those included in the foregoing notices, have been made known since the 10th of September, 1890:—

Members.

BALLARD, STEPHEN; *born* 1804; *died* 14 November, 1890.

GALLWEY, LIONEL PHILIP PAYNE; *born* 7 July, 1851; *died* January, 1891. (*Fever.*)

HUTTON, ROBERT JOSEPH, B.A.; *born* 22 April, 1842; *died* September, 1890. (*Hæmorrhage of the brain.*)

MACNAB, ALEXANDER; *born* 18 March, 1837; *died* 4 January, 1891.

RUSS, WILLIAM; *died* 13 February, 1891, *aged* 62.

SCOTT, MICHAEL, F.R.S.E.; *born* 4 August, 1818; *died* 13 September, 1890. (*Gout.*)

STOTHERT, JOHN LUNS; *born* 29 June, 1829; *died* 5 March, 1891, *aged* 62. (*Heart disease.*)

Associate Members.

BOURDEAUX, JOHN; *born* ; *died* 2 July, 1890.

DIXON, JOHN; *born* 1835; *died* 28 January, 1891.

HINGESTON, CHARLES HILTON; *born* 14 May, 1858; *died* 1 October, 1890. (*Malarial fever.*)

MAGEE, WILLIAM SNELL TANDY, M.E.; *born* 3 July, 1861; *died* 14 May, 1889. (*Fall from the scaffolding of a water-tower.*)

MUSGRAVE, JOSEPH; *born* 10 March, 1812; *died* 12 January, 1891. (*Bright's disease.*)

ROEHRICHT, RICHARD HUGO OSWALD; *born* 8 January, 1834; *died* 1890.

SAUNDERS, EDWARD ROBERT; *born* 7 June, 1857; *died* 28 December, 1890.

SPON, ERNEST; *born* 1 August, 1849; *died* 28 November, 1890. (*Syncope.*)

STOLLMEYER, ANDRE BLASINI; *born* 5 December, 1858; *died* 22 December, 1890.

Associates.

ESTRIDGE, *Lt.-Col.* JOSEPH, *late* R.E.; *born* 27 August, 1811; *died* 7 December, 1890.

PARKER, *Captain* GEORGE CHARLES; *born* 19 February, 1836; *died* 15 November, 1890.

RADCLIFFE, JOHN ALEXANDER; *born* 26 February, 1823; *died* 27 January 1891.

WRIGHT, THOMAS; *died* 20 February, 1891, *aged* 79.

Information respecting the life and works of any of the above is solicited in aid of the preparation of Obituary Notices.—SEC. INST. C.E., 10 *March*, 1891.

SECT. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

The Paris Laboratory for Testing Materials. By R. AUDRA.

(Le Genie Civil, vol. xvii., 1890, p. 402.)

This laboratory was begun in a very humble way in the year 1867 by a grant of £16 from the administration of Ponts et Chaussées, it having been found that some of the materials sent in by contractors for paving were not up to the standard required. It has since grown until at present 30,000 tests per annum are made on all kinds of materials, including cements, asphalts, stones, and metals. Formerly France was obliged to go abroad for cement, but by means of analyses carried out in this laboratory she is now able to supply all her needs at home. At first the laboratory was placed in an old kitchen on the third floor of the octroi office, and by degrees extended, until now a new building has been specially erected for it forming three sides of a square with an open space in the centre. In one of the divisions on the ground floor are placed the apparatus for testing paving materials, driven by a gas engine of about ½ HP.; and next to the chamber is one containing the hydraulic press used for compression tests, and special foundations have had to be put down. The basement is used for the preparation of briquettes, and for the immersion tanks. The Author gives details of the space occupied by the chemical laboratory. The hydraulic press is capable of exerting a pressure of 150 tons per square inch, and is provided with three pressure-gauges, of which two indicate up to 30 tons, and should give readings which agree with the third. The apparatus used for testing paving materials are two in number, one for stone sets, the other for macadam.

The action of the first is as follows: A sample of regular shape of the rock to be tested is placed upon a surface rotating in a horizontal plane, and a certain pressure applied to the specimen upon one of its plane faces; the wear is then compared with that of a block of standard material under the same conditions. The coefficient of wear is the proportion between the volumes worn away. If v and v' represent these volumes and p and p' the weights, and d and d' the densities, then—

$$C = \frac{v}{v'} = \frac{p\,d}{p'\,d'}$$

Mixture.	Tension. Tensile Strength after		Compression. Compressive Strength after		Ratio.	
	7 Days.	28 Days.	7 Days.	28 Days.	Tension for 7 days.	Compression to 28 Days.
Pozzolana Cement I.						
	Lbs. per Sq. Inch.	Lbs. per Sq. Inch.	Lbs. per Sq. Inch.	Lbs. per Sq. Inch.		
1 to 3. By Weight. Water .	137·0	266·0	836	1860	$\frac{1}{6\cdot031}$	$\frac{1}{7\cdot024}$
1 to 3. By Weight. Air. .	89·8	118·0	910	1355	$\frac{1}{10\cdot127}$	$\frac{1}{11\cdot377}$
1 to 3. By Volume. Water .	65·8	161·0	412	940	$\frac{1}{6\cdot269}$	$\frac{1}{5\cdot876}$
1 to 3. By Volume. Air .	59·5	64·7	465	590	$\frac{1}{7\cdot861}$	$\frac{1}{9\cdot099}$
Pozzolana Cement II.						
1 to 3. By Weight. Water .	237·0	324·0	2350	3650	$\frac{1}{9\cdot952}$	$\frac{1}{11\cdot242}$
1 to 3. By Weight. Air. .	185·0	203·0	2210	2530	$\frac{1}{11\cdot985}$	$\frac{1}{12\cdot455}$
1 to 3. By Volume. Water .	174·0	223·0	1423	2280	$\frac{1}{8\cdot163}$	$\frac{1}{10\cdot332}$
1 to 3. By Volume. Air. .	129·0	135·0	1290	1480	$\frac{1}{10\cdot044}$	$\frac{1}{10\cdot989}$
Pozzolana Cement III.						
1 to 3. By Weight. Water .	202·0	298·0	1575	2620	$\frac{1}{7\cdot788}$	$\frac{1}{8\cdot800}$
1 to 3. By Weight. Air. .	174·0	256·0	1415	2230	$\frac{1}{8\cdot114}$	$\frac{1}{8\cdot665}$
1 to 3. By Volume. Water .	99·0	183·0	668	1165	$\frac{1}{6\cdot714}$	$\frac{1}{6\cdot372}$
1 to 3. By Volume. Air. .	58·0	70·0	550	847	$\frac{1}{9\cdot439}$	$\frac{1}{11\cdot842}$

TABLE I—*continued.*

Mixture.			Tension. Tensile Strength after 7 Days.	Tension. Tensile Strength after 28 Days.	Compression. Compressive Strength after 7 Days.	Compression. Compressive Strength after 28 Days.	Ratio. Tension for 7 Days.	Ratio. Compression for 28 Days.
				Portland Cement IV.				
			Lbs. per Sq. Inch.	Lbs. per Sq. Inch.	Lbs. per Sq. Inch.	Lbs. per Sq. Inch.		
1 to 3.	By Weight.	Water .	266	297	1892	2854	$\frac{1}{7\cdot168}$	$\frac{1}{9\cdot581}$
		Air. .	257	335	2025	2980	$\frac{1}{7\cdot862}$	$\frac{1}{8\cdot892}$
	By Volume.	Water .	216	274	1735	2600	$\frac{1}{8\cdot046}$	$\frac{1}{9\cdot531}$
		Air. .	226	285	1920	2820	$\frac{1}{8\cdot497}$	$\frac{1}{9\cdot875}$
				Portland Cement V.				
1 to 3.	By Weight.	Water .	219	283	1715	2680	$\frac{1}{7\cdot812}$	$\frac{1}{9\cdot487}$
		Air. .	228	297	1830	2820	$\frac{1}{7\cdot950}$	$\frac{1}{9\cdot519}$
	By Volume.	Water .	172	243	1310	2150	$\frac{1}{7\cdot597}$	$\frac{1}{8\cdot891}$
		Air. .	188	283	1410	2240	$\frac{1}{7\cdot500}$	$\frac{1}{7\cdot895}$
				Portland Cement VI.				
1 to 3.	By Weight.	Water .	211	273	1735	2690	$\frac{1}{8\cdot277}$	$\frac{1}{9\cdot793}$
		Air. .	237	304	1860	2800	$\frac{1}{7\cdot886}$	$\frac{1}{9\cdot265}$
	By Volume.	Water .	203	265	1535	2490	$\frac{1}{7\cdot594}$	$\frac{1}{9\cdot378}$
		Air. .	228	278	1715	2670	$\frac{1}{7\cdot497}$	$\frac{1}{9\cdot608}$

TABLE I—*continued.*

Mixture.		Tension. Tensile Strength after		Compression. Compressive Strength after		Ratio.	
		7 Days.	28 Days.	7 Days.	28 Days.	Tension for 7 Days.	Compression for 28 Days.
			Roman Cement VII.				
		Lbs. per Sq. Inch.	Lbs. per Sq. Inch.	Lbs. per Sq. Inch.	Lbs. per Sq. Inch.		
1 to 3. By Weight.	Water .	40·5	121·5	300	882·0	$\frac{1}{7\cdot404}$	$\frac{1}{7\cdot310}$
	Air. .	111·5	200·0	530	114·9	$\frac{1}{4\cdot769}$	$\frac{1}{5\cdot628}$
1 to 3. By Volume.	Water .	18·5	54·1	123	322·0	$\frac{1}{6\cdot692}$	$\frac{1}{5\cdot917}$
	Air. .	58·2	940·0	178	488·0	$\frac{1}{3\cdot049}$	$\frac{1}{5\cdot797}$

Further, in Pozzolana cement the loss decreases a little between 7 and 28 days in the water-hardened tests, and increases in the air-hardened ones; the loss is also greater in the compressive than in the tensile tests.

In Portland cement the loss in the water-hardened tests after 7 days is greater than after 28 days. In the air-hardened tests these results are not noticeable, and the loss in compressive tests is greater than in tensile tests. For Roman cement the loss increases in the water-hardened tests from 7 to 28 days, while in the air-hardened tests this is only the case in the tension tests: the loss is also greater in the compression tests than in the tensile tests.

Now comparing these results with the established values given by the Prussian rules above referred to of

227·5 lbs. per square inch in tension,
2275 lbs. per square inch in compression,

for mortars consisting of 1 part cement + 3 parts sand, by weight, which has been hardened for 1 day in air and then for 27 days in water, and placing the results of the water-hardened tests, by weight and by volume opposite each other, the following table can be constructed:—

TABLE II.

		Tension. Lbs.	Compression. Per Sq. Ins.
Pozzolana cement I.	by weight	266	1,860
	by volume	161	940
Pozzolana cement II.	by weight	324	3,650
	by volume	223	2,280
Pozzolana cement III.	by weight	298	2,620
	by volume	183	1,165
Portland cement IV.	by weight	297	2,855
	by volume	274	2,600
Portland cement V.	by weight	283	2,680
	by volume	243	2,150
Portland cement VI.	by weight	273	2,690
	by volume	265	2,490
Roman cement VII.	by weight	121	882
	by volume	54	332

L. S. R.

Horizontal Concrete-Machine driven by Steam-Power.

By J. FOY.

(Annales Industrielles, 12 October, 1890, p. 474.)

For mixing small quantities of concrete manual labour has hitherto been considered sufficient, but for large quantities it is necessary to use other means, and many machines worked by steam-power have been devised. When concrete is mixed by hand, the cement or mortar is first mixed or gauged, and then spread out, a layer of broken stones being laid over it; then another layer of cement and a second layer of broken stones, and so on until sufficient of both have been collected in alternate strata. The whole heap is then turned over with shovels until a complete mixture is made. This method, although primitive, answers well for small quantities, and very excellent concrete is thus made, not surpassed by that produced by machines. An early machine consisted of boxes of cast-iron, and from six to ten men were employed in the process, the result being 45·77 cubic yards in ten hours, at a cost of about 14 pence per cubic yard. Another machine consists of a rectangular wooden box about 3 feet 3 inches long, 2 feet 8 inches wide, and about 8 feet 2 inches long, with a lateral opening 3 feet 3 inches long by 2 feet high provided at the bottom for the concrete to pass out. Near the top of the box an inclined plane of wood covered with sheet iron is fixed, below this a second plane inclined in the opposite direction, and again below this a third plane inclined the same way as the first. The materials, cement and broken stones fall from one plane to the other, and finally pass out at the lower opening. This machine will produce 78 cubic yards of concrete per day, at a cost of about 9 pence per cubic yard.

Many builders prefer the vertical concrete machines, which may frequently be seen in use for house building in Paris; these

furnish concrete of fair quality, but hardly in sufficient quantity for very large works, such as docks and fortifications, where great quantities are required to be mixed and used in a short time.

The horizontal machine by Messrs. Coster, Rikkers & Co., of Saint-Denis, claims to satisfy this requirement. It is composed essentially of a cylinder of plate iron with its axis inclined slightly to the horizon, and furnished inside with paddles; the cylinder is carried on rollers fixed to an iron frame, and is turned by bevel gearing, and a counter-shaft, the latter being driven by a belt. A hopper with a feed-gate is provided at the upper end, and is carried on an iron frame.

A plate-iron box is fixed to the framework at the lower end of the cylinder to receive the mixed materials. One of these machines will furnish 654 cubic yards of concrete per day, and may be driven by a 10-HP. portable steam-engine. The machine is placed so that the hopper is level with a stage, and the materials are fed in from little trucks of a known capacity. The cylinder makes 10 revolutions per minute, and is provided with forty paddles, so that the materials receive 400 blows per minute. The stones and cement are measured by means of the trucks, and the water by means of an adjustable valve. These machines have been adopted to accelerate works at Toul, Verdun, Champagne, and other places.

An illustration of the machine is given, but the dimensions are not stated, only the outside view in perspective being shown.

H. H. P. P.

Road-bridge over the North Elbe at Hamburg.

By C. O. Gleim and H. Engels.

(Zeitschrift für Bauwesen, 1890, p. 219.)

The axis of the bridge is parallel to that of the existing railway bridge, and above it at a distance of 244 metres (800 feet); it is designed in accordance with it, in three spans of 102 metres (335 feet), on the principle of the Lohse girder. Eventually it will be a double bridge, the additional structure being planned to carry a double line of rails. The clear width between the girders is 7·6 metres (25 feet), giving room for two tramways, and a space of 2·5 metres (8 feet 2½ inches) between them for large road vans. Footpaths of 2 metres width each are on cantilevers outside the girders.

The Lohse girder consists of an upright braced arch and an identical inverted arch, both joined together at the springing, and connected by vertical tie-rods; the girder lies entirely above the platform. The present girder has twenty-six panels, the end-panels being 4·30 metres (14 feet), and the intermediate panels 3·85 metres wide. The two flanges of each arch have a constant vertical distance of 3·10 metres from each other, and are arranged

as polygons with equal angles at each point; in consequence of this arrangement the axis lies almost exactly in a parabola. The section of each flange is an H composed of three plates, eight angle-bars, and two vertical packings behind the inner angle-bars; the packings are replaced by plates at the junctions of diagonals and verticals, and cover strips render them available for sectional area. The pitch of the rivets is very uniform, beginning with a space of 90 millimetres ($3\frac{1}{2}$ inches) on the corner of the polygon, then followed by 80 millimetres within the region of the connection and 200 millimetres beyond it; the rows of rivets are in lines at right angles with the axis of the parts. The diameter of the rivets is 26 millimetres (1 inch) and 23 millimetres respectively, the plates are 14 millimetres, and the angle-bars from 10 to 16 millimetres thick.

The verticals in the arches consist of four angle-bars, the diagonals of two tee-bars, and the verticals between the arches of one H-bar. Two large plates illustrate these details and the connection of the end panels.

Each flange of one upright arch is connected independently by transverse bracing with the corresponding flange of the other, the bracings being connected only at the piers. They consist of braced horizontals and flat-bar diagonals, all these parts being connected by two angle-bars running from end to end in one-third and two-thirds of the space between the arches. The inverted arches have no transverse bracing, but they are connected to the cross-girders of the platform by braced uprights.

All bearings of the main girders are ou pivots whose bed-plates are about 7·2 metres (24 feet) above the platform. Those on the land-piers are fixed, and rest on the stone masonry of the grand gates (illustrated by copper phototype). The remaining four bearings on the two river-piers, except one, are on rollers, and rest on wrought-iron riveted standards 2 metres by 0·8 metre about 9 metres high.

The cross-girders are 3·85 metres apart, and there are two longitudinal H-bar bearers under the track of the heavy road-vans in the middle, one lighter bearer under each tramway and two outer riveted stringers; the roadway plates 8 millimetres ($\frac{5}{16}$ inch) thick are cylindrical and inverted, carrying the concrete and granite pavement over a span of about 1·56 metre with a versed sine of 1 in 10. The horizontal strain is taken by two flat bars in every panel bedded in the concrete.

The statical calculation of the platform is based upon the assumption of one vehicle with a weight of 18,000 kilograms (say 18 tons) and a wheelbase of 4 metres by 1·4 metre in the middle of the roadway, and two vehicles with a weight of 10,000 kilograms and a wheelbase of 3·5 metres by 1·4 metre. For the main girders vehicles with a weight of 6,000 kilograms are assumed on the side tracks, and of 10,000 kilograms for the middle tracks. This load is, so far as the main girders are concerned, equivalent to 350 kilograms per square metre (72 lbs. per

square foot). The load on the outer footpaths is assumed at 450 kilograms per square metre. The total moving load upon one main girder is accordingly 2,660 kilograms per lineal metre, while the weight of the platform is 4,710 kilograms, and that of the main girder 2,530. The corresponding weights of the above-mentioned railway bridge were 3,185, 1,335, and 2,180 kilograms respectively.

The strain on the iron is taken, according to the Launhardt-Weyrauch formula, at—

$$\left(1 + \frac{\min P}{2 \max P}\right) \times 700$$

kilograms per square centimetre. Consequently the average strain in the flanges of the arches is 920 kilograms per square centimetre, while in the railway bridge it is 730 kilograms. Additional strength is given to parts in compression according to their length; the shearing strain in the rivets is taken at $\frac{4}{5}$, and the pressure in the rivet-holes at $\frac{4}{3}$ of the tensile strain. A wind-pressure of 150 kilograms per square metre (30·5 lbs. per square foot) is assumed for the bridge, when loaded, and of 280 kilograms when unloaded. In addition to the surface of the elevation one half of that of the second girder is assumed. The strain on parts exclusively strained by wind-pressure is taken at 1,400 kilograms per square centimetre.

For the calculation of the horizontal strain in the arches it was admissible to assume a pivot at the springing, but not at the crown. The formula used is by Müller-Breslau, viz. :—

$$H = P \frac{3\,a\,(l - a)}{4\,f\,l},$$

a formula abbreviating some more complicated expression comprising the axial shortening as well as the transverse bending of the arch. P is a single load; a, the distance of it from the springing; l, the span, and f, the rise of the arch. The distribution of the shearing forces among the diagonals of a panel was determined according to Mohr's method.[1] The bending-strains resulting from the one-sided attachment of the tee-bar diagonals were also calculated and added.

The concrete foundations for the river-piers go down to a depth of 1·2 metre (4 feet) below the bed of the river after dredging, the ground being sand and gravel, condensed by the piles which are driven to a depth of 6·9 metres (22·8 feet). The concrete is composed of one part of trass to one part of lime and four parts of broken granite, trass being used in place of Portland cement, as it sets more slowly. The masonry beginning 4·3 metres above the bed of the river consists of brick with ashlar of limestone and basalt

[1] Zeitschrift des Architekten- und Ingenieur-Verein zu Hannover, 1874.

lava, then vitrified bricks, and, finally, basalt lava. The pressures are 21 kilograms per square centimetre (19¼ tons per square foot) on the basalt, 7 kilograms to 4 kilograms per square centimetre on the brickwork, 4 kilograms on the concrete, and 3·6 kilograms on the ground.

The works were begun in 1884 and completed in the autumn 1888.

The expenditure was as follows:—

	Marks.
For temporary buildings, excavation, masonry, &c. (given in detail)	1,332,302·65
For iron structure	790,073·46
„ roadway, railing-lamps, &c.	164,562·23
„ management and supervision	174,128·66
Sundries	5,261·11
	2,466,328·11

or about £123,000. The cost of the railway bridge was 2,084,195 marks.

M. A. E.

The Erection of the Second Bridge over the Vistula at Dirschau.

By A. Goering.

(Centralblatt der Bauverwaltung, 1890, p. 323.)

The new bridge, whose centre-line is only 40 metres from that of the old single-line bridge, had to be constructed according to the position of the piers of the latter. It has therefore six spans of 130·88 metres each between centres of piers and two lines of railway, while the old bridge, with one line and a single track for road traffic, will henceforth be used for road-traffic only. The old bridge, built between 1850 and 1857, marks a step forward since the Britannia Bridge (1845–1850) with a clear span of 139·5 metres, as a multiple flat-bar web was the first time used instead of the plate-web; it is still the largest bridge of this kind, and next to the Kuilenburg Bridge, still the largest girder-bridge on the Continent of Europe.

The main girders of the new bridge are fish-girders, 18 metres deep in the centre and 3·36 metres at the ends; the bottom flange is in the middle 1·3 metre and at the ends 8·6 metres above the rail-level, which is 12·87 metres above mean water-level; the web has a double system of diagonals which intersect each other in a horizontal line; between the points of their attachment to the flanges, which are 7 metres apart horizontally, the latter are straight; the platform is suspended by vertical bars, 7 metres apart, from the bottom flange, and there are only two verticals at each end of the girder. The cross-section of the flanges consists of two adjoining vertical crosses 0·9 metre high and 0·5 metre

broad, made of several thicknesses of plates and four angle-irons; bending of parts is entirely avoided. Longitudinal stringers, 7 metres long, are placed under each rail and under the parapet railings. Cross-bracing occurs only between the top flanges of the main girders and between the bottom flanges of the stringers. The latter consists of a primary system between the outer stringers 9·9 metres apart, and a secondary system between the next stringers 5 metres apart, both systems resisting according to their respective deflections. The four supports of each main girder have each a different construction; one is fixed, one movable crossways, one movable lengthways, and one movable both ways; in the last there are two sets of rollers one over the other crossways. The platform is made of trough-irons laid 0·7 metre apart crossways over the stringers; they serve as sleepers carrying the rails and the longitudinal planking. The total weight of metal in the superstructure, including bed-plates, is about 6,600 tons, viz., 300 tons of ingot-iron, 100 tons steel, and the rest wrought iron. The weight of the old bridge is about one-third greater.

The five river-piers are of brickwork faced with granite, and have a cornice under the level of the platform. Their width, under the cornice, is 6 metres, and their length 18 metres. As the bottom of the main girders, at their ends, is 8·6 metres above the platform, a flat granite arch rises from the platform up to that height. Of this arch the abutments are 4·2 metres thick, and the clear span 8 metres, allowing the passage of the railway trains. As the platform of the bridge near the piers is 10·1 metres wide, the loss of the 2·1 metres is made up by a footway passing round the abutments on the cornice. The shore piers will also have this arch as part of a great entrance gate in the style of that of the old bridge.

The foundations of the piers consist of a bed of concrete 3·8 metres thick, 23·7 metres long, and 18·82 metres wide, resting on timber piles at a level of 3·9 metres below low-water (4·8 metres below mean-water) the river having been dredged to that level; the concrete is enclosed by a wall of sheet piling. Outside of this an extensive dam of granite boulders from the Baltic Sea reaches up to the top of the concrete. The masonry begins here with a width of 8·34 metres.

Previously to the sinking of the concrete by means of a movable iron funnel, the inner surface of the sheet-piling was lined with canvas between the bed of the river and the top, 7 metres above it. On the top of the concrete and 1 metre within the sheet-piling, another timber wall was erected, the piles being slightly driven into the concrete, and its outer surface was also lined with canvas. The space between the two sheets of canvas was filled with sand, the whole formed a cofferdam from which the water could be pumped out within a few hours and the surface of the concrete be prepared for receiving the masonry.

For the erection of the iron superstructure a stage was made and entirely covered with planks; it was surmounted by scaffolding

carrying a traveller at a height of 20 metres above the planking, clearing the top of the iron structure, the rails being 12 metres apart. Works commenced after the floods on May 10, 1888; and while the scheme of erection includes four complete building seasons, they have already advanced so far that only the iron superstructure of two spans will remain to be erected during the fourth season. In connection with these works are a similar but shorter bridge over the Nogat, the reconstruction of the station at Dirschau, and extensive works for regulating the river, altogether estimated to cost 15 million marks.

The designs were made and the works superintended by the Prussian Government engineers, Schwedler and Mehrtens; contractors for the ironwork are the Harkort Company of Duisburg, Westphalia.

M. A. E.

The Collapse of the Karls-Bridge at Prague, and Accident during the Erection of the Exhibition Hall.

By Professor T. MELAN.

(Wochenschrift des oesterreichischen Ingenieur- und Architekten-Vereines, 1890, p. 321.)

The Author ascribes the collapse of the historically venerable bridge to the scouring of the floods under the probably shallow foundations of the piers, increased by the circumstance that half the bridge was blocked by drift timber.

The erected portion of the Exhibition hall consisted of two double three-hinged arch-ribs, 25 metres (82 feet) high, with a span of 40 metres (131 feet), the single ribs being 5 metres (16 feet), 15 metres (50 feet), and 5 metres (16 feet) apart. Wind-bracing was to be introduced only in the end bays of the building. The Author ascribes the collapse of the structure—which happened after the workmen had left—to insufficient temporary bracing, especially at the apex hinge, and draws from it the lesson that three-hinged arches, especially high ones, should be treated with care, and their theoretical advantages in some cases be relinquished in favour of the two-hinged arch.

M. A. E.

The Ohio Bridge of the Cincinnati and Covington Elevated Railway. By W. H. BURR, M. Am. Soc. C.E.

(Transactions of the American Society of Civil Engineers, vol. xxiii., 1890, p. 47.)

This structure carries the line of the Chesapeake and Ohio railroad system across the Ohio at Cincinnati, and presents some points of especial interest owing to the magnitude of the discontinuous steel girders which span the principal openings. The

the approaches are extended on each side in spans of smaller dimensions.

The three principal openings are spanned by independent girders of polygonal form, carried upon masonry piers at a clear height of 120 feet from the bed of the river to the horizontal lower member of the girder.

The central truss, having a length of 545 feet and a depth of 84 feet between pin centres, forms the largest discontinuous span that has yet been erected, while all the spans are of unusual weight owing to the fact that they carry a double line of railway together with two carriage-ways, and two side-walks, the bridge platform having a width of 67 feet between parapets.

The main trusses are placed at a transverse distance of 30 feet, centre to centre, and carry the double line of railway between them; but on each side the cross-girders project nearly 20 feet beyond the trusses, each cantilever serving for the support of a wagon-road, 11 feet in width, running immediately outside the truss, together with a footway on the outer side.

In designing the steel superstructure, especial precautions were taken for annulling, as far as possible, all secondary stresses, and eliminating every ambiguity in the principal stresses.

With this view the web-bracing of each truss is confined to a single system of vertical posts and inclined ties, the bays having a uniform width of 54 feet 3 inches; but an intermediate support is provided at the centre of each bay by means of a vertical, which is supported by the diagonal tie and a counter-brace, and which divides the roadway platform into panels of 27 feet 1½ inch, the cross-girders being fixed at this distance apart. In executing the work, each member was bored to such adjusted length, between connections, as would annul all secondary stresses at a condition of loading intermediate between no moving load and a full moving load; and in the upper compression member the pin-centres were adjusted slightly below the centre of gravity of the section, with the view of partly counteracting the bending stress due to its unsupported weight.

The cross-girders are so attached as to bring their weight centrally upon each truss. At each panel-point the lower member of the main truss passes through an opening in the web of the cross-girder just above its lower flange, while the upper flange of the cross-girder passes through the web of the vertical post, and the supporting attachment is made by bolts, acting in shear only, and turned to fit tightly in holes bored in the intersecting webs and connecting angle-bars.

The cross-girders, stringers, and wind-bracing are of wrought iron, while the main trusses are built of steel throughout, and consist of members which differ but little, in their form, from the usual American practice. Every tension-member is composed of steel eye-bars, which are generally 7 inches in depth, placed in a

single rank and coupled by pin-connections, the pins of the lower chord being 7⅝ inches in diameter, and reaching a length of nearly 7 feet in the centre of the span. The pins and the 7-inch eye-bars were forged from open-hearth steel, while a few 8-inch bars were forged from Bessemer steel. The upper boom is an inverted trough with a width and depth of 30 inches; while the posts, which reach a height of 84 feet, are of box section, about 20 inches by 23 inches in outside dimensions, with two sides of open lattice. The posts are stayed transversely by the sway-bracing, and longitudinally by a central stay.

The entire superstructure was designed and executed by the Phœnix Bridge Company under a specification which was proposed by them and accepted by the railway company, and which defines the leading dimensions of the bridge, the loads and other straining forces to be provided for, the working stress to be adopted in the different members, and the tests to be applied to the different materials.

The specified straining forces, in addition to the actual weight of the structure, include:—(*a*) a moving load on each railway track consisting of a train weighing 2,500 lbs. per lineal foot headed by two engines with specified wheel-loads; (*b*) a distributed load of 60 lbs. per square foot on all carriage and footways; (*c*) an alternative load of 80 lbs. per square foot on one side only, with a concentrated load of 15 tons on 10 feet; (*d*) an additional allowance for the impact of the railway live load, amounting to 25 per cent. in some members and 50 per cent. in others; (*e*) a wind-pressure of 30 lbs. per square foot on each truss and on one train; and (*f*) the frictional resistance of bed-plates or roller-bearings estimated at 25 per cent. of the load.

As regards working-stress, the specification allows a higher value for wind-stresses than for load. For the latter, the working-stress in iron and in steel is specified for shearing and transverse bending and for bearing-pressure. The allowed tensile stress varies in different members, being fixed at 16,000 lbs. in the steel eye-bars of the lower chord, and at 13,000 lbs. in the central braces. The compressive stress in wrought-iron is defined by five different formulas; while in the steel boom of the main trusses it is fixed at 14,000 lbs. per square inch, provided that the ratio of length to radius of gyration does not exceed 50. The allowed compressive stress in the steel posts is expressed by a formula of the Gordon type, with a further reduction for stress-variations.

As regards quality of material, the maker is not restricted to any class of steel or any process of manufacture, but the requirements are defined by mechanical tests. The prescribed tensile strength of iron bars and plates, per square inch, varies with the scantling of the bars or the width of the plates. Steel for tension members is to have an average strength of 62,500 lbs., and for compression members a tensile strength of 68,000 lbs. per square inch, subject to a maximum variation of 4,000 lbs. below these figures in any individual bar. The elastic limit is to be at least

contraction of area are specified as varying inversely with the tensile strength, the required percentage of elongation being expressed by $\frac{1,200,000}{\text{tensile strength,}}$ as measured upon a length of ten diameters.

The results of the actual testing are given in detail in the Paper, and the specified tests were supplemented by other experiments to ascertain the effect of various shop manipulations on plates and rivets. These trials demonstrated the reliable character of the steel in every respect. In the case of a few broad and heavy forgings the makers experienced a good deal of difficulty; but this was overcome as soon as they had discovered the importance of putting enough work upon the metal, between the ingot and the finished plate.

The total quantity of steel and iron contained in the three principal spans is almost exactly 10,000,000 lbs.

The two river-piers, at the ends of the central span, are founded upon timber caissons carried down to the bed-rock at a depth of about 54 feet below low-water; while the foundations of the shore-piers are laid upon piled platforms, the weight being distributed over the area of each platform by widely-splayed footing-courses. The piles are spaced at 4 feet centres in each direction, and driven to refusal, 30 to 42 feet into the clay and gravel of the banks. The heads are covered by a solid platform of 12-inch timbers laid on 12-inch longitudinal pile-caps; and the maximum load per pile amounts to 81,200 lbs.

The caissons for the foundation of the river-piers are built with splayed sides, battering 1 in 15, and at the cutting-edge they each measure 81 feet 3 inches by 34 feet 10 inches in plan. The working-chamber is 8 feet 9 inches in height from the cutting-edge to the roof, the walls being 4 feet thick and composed of three shells of 12-inch timbers with four shells of 3-inch sheathing between and outside them, the outer sheath being well caulked. The roof is formed of seven solid layers of 12-inch timbers, laid alternately in transverse and longitudinal directions, and ceiled with 3-inch pine sheathing; and above the roof, the caisson is carried up for a further height of 36 feet with an outer shell of 12-inch timbers tied in both directions by cross-walls of timber, forming an open grillage or crib-work, and dividing the area into twelve square pockets, which are filled with concrete composed of 1 part of Louisville cement to 1 of sand and 3 of broken stone. The masonry pier is bedded upon the top of the crib-work at a depth of 5 feet below low-water.

The working chamber was stayed internally by timber ties, and provided with a working-shaft 4 feet in diameter, an excavating-shaft, and a central concreting-shaft which was used only for supplying the concrete with which the chamber was ultimately filled. A number of 4-inch ascending pipes were also carried through the roof, projecting about 6 feet below it, and were used

for discharging the sand and excavated gravel by air-pressure, the greater part of the material being removed by this means.

The pneumatic machinery and electric lighting plant were carried in two large barges, which were moored alongside the caisson, and were fitted with complete machine-tools and appliances for the maintenance of the plant.

Each caisson and crib contains about 520,000 feet of timber (board measure) and 3,600 cubic yards of concrete; while the pier above it contains about 4,900 cubic yards of masonry. The launching and sinking of a caisson, together with the building and concreting of its crib, occupied an average period of one hundred and twenty-six working days, and the building of the masonry pier one hundred and thirty-five working days.

The construction of the great steel spans was commenced in the shops in March 1888, and the bridge was completed for traffic on December 25th of the same year. The spans were erected upon false-work carried on piling, but the work was interrupted by floods of unusual violence, which on one occasion forced the staging of a 490-foot span about a foot down-stream, and shortly afterwards carried away the entire staging of the central span, together with 300 tons of iron and steelwork that had been placed in position upon it. The cause of this collapse was the undermining of the piles by a scour which was assisted and partly induced by the collection of drift that was brought down by the flood, and which formed a continuous mass extending 500 feet up-stream. But the staging was at once rebuilt, and the steelwork recommenced, and by working without intermission, the structure was completed within the time named.

T. C. F.

The Ohio Connecting-Railway Bridge.[1]

By C. L. Strobel, M. Inst. C.E.

(Engineering News, New York, vol. xxiv., 1890, pp. 253 and 276.)

The great span of 523 feet for the main channel of the Ohio River—being a girder-bridge of 65 feet depth, and 25 feet width, and weighing 915 tons—was successfully floated in place on August 23rd, 1890, after it had been erected on timber trestle-work 73 feet high above water-level, alongside the shore, at a clear distance from the pier of about 300 feet. The trestle-work consisted of two stages, viz., the lower one 16 feet high above water-level, with nine openings for the admission of nine barges, and the upper one, resting upon it, 57 feet high, which was braced longitudinally as well as transversely; at the bottom it was 80 feet

[1] Photographs illustrating the great span, and the operation of floating it into position, have been presented to the Institution by Mr. Strobel.

wide, and at the top 32 feet. The barges were floated into the openings partially sunk, and the water was pumped out for lifting the main trestle with the bridge off its fixed supports. The structure was then towed parallel to its original position until one end was in place and then swung round; water was let into the barges, and the day's work was stopped when the girder was within 9 inches of its seat. The following morning it was guided to its final position by means of the anchor-bolts.

The article is illustrated by three perspective views and by small scale drawings.

M. A. E.

The Red Rock Cantilever Bridge.

(Engineering News, New York, vol. xxiv., 1890, pp. 274 and 303.)

The anchor-arms are 165 feet long in six panels, the lever-arms are also 165 feet long, and the suspended girder 330 feet long in twelve panels; the middle span is therefore 660 feet. The depth is 101 feet over the piers and 55 feet in the middle. The distance between the centres of the two girders is 25 feet. The river-piers are of stone masonry, and their foundations of concrete of 1 part cement, 3 parts sand, and 4 parts stone. The pier to the east was sunk 61 feet below low-water, where a hard bed of boulders was reached, about 20 feet above the rock. The caisson 60 feet long and 30 feet wide at the bottom, with a batter of 1 in 16, was made of timber, generally 12 by 12 inches thick. the excavating chamber was 54 feet long, 24 feet wide, and 8 feet 9 inches high; the walls consisted of three courses, and the decking of eight courses of 12-inch timber; the space was divided into twelve working pockets by means of cross-timbers 16 inches thick.

The iron structure begins a little above high-water, but the suspended girder is 41 clear feet above it. Stating the axle-weights in lbs., and the distances in inches, alternately, the load-diagram of an engine is as follows:—

60, 11,000; 68, 11,000; 54, 30,666; 61, 30,666; 79, 30,666; 135, 18,500; 65, 18,500; 66, 18,500; 48, —.

then follows the second engine, and then a distributed load of 3,000 lbs. per foot lineal. A wind-pressure of 30 lbs. was assumed. The wind-bracing is made of rods and struts between the top chords throughout the bridge, and also between the bottom chords of the suspended span, and of stiff members between the bottom chords of the lever- and anchor-arms. The wind-pressure in the top chord of the suspended span is conducted through the portal-bracing at its ends down to the bottom-bracing of the arms. At the junctions of the suspended span with the lever-arms, adjusting wedges were inserted in the top and bottom chords in order to obtain a perfect touch of the iron parts in the centre of the span at

the close of the erection. These wedges were drawn directly after the touch was effected. A traveller was used running on the top of the floor of the bridge, which is placed on the bottom chord of the suspended span, its top stage being about 10 feet above the highest point of the truss.

The whole structure weighs about 1,560 tons, and was erected in eighty working days, with about seventy-five hands on the average. The cost of the substructure was 232,300 dollars, and of the superstructure 230,160 dollars. The designer of the bridge was Professor J. A. L. Waddell; the consulting engineer Professor S. W. Robinson; the contractors Messrs. Sooysmith & Co. and the Phoenix Bridge Co., and the chief engineer of the Atlantic and Pacific Railroad, Mr. S. M. Rowe.

The article is illustrated by several woodcuts and a lithographed drawing.

M. A. E.

On the Treatment of Slips on the Illawarra Railway at Stanwell Park (N.S.W.). By W. Shellshear, Assoc. M. Inst. C.E.

(Proceedings of the Royal Society of N.S.W., 1890, p. 58, 1 plate.)

During the construction of the Illawarra Railway considerable difficulty was experienced from slips in the cuttings. The first year after the line was opened (1888) being a tolerably dry period, no serious trouble ensued, but the results of the great rainstorm of May 25, 26 and 27, 1889 (during which more than 20 inches of rain fell), were most serious. On the date last named, besides other damage, the embankment at 33 miles (from Sydney) slipped out bodily from the bed rock, leaving the ends of the sleepers overhanging about 4 feet. Every effort was made to repair the road, and traffic was resumed on the 31st of May; but the slip still continued, and, after carefully examining the ground, the Author found that the only chance of saving the embankment was to put in an extensive system of drainage, and thus if possible to consolidate the ground above the bed-rock. The great depth of the soil and the enormous mass of material to be kept back made retaining-walls out of the question. At the site of the slip the cliff was about 150 feet above sea-level, and was composed of sandstone with beds of shale. The surface-soil, varying in thickness from 1 to 30 feet, rested upon a bed of chocolate-coloured shale with numerous veins of pipe-clay. The dip of the strata being slightly inclined inwards afforded a recess at every break of strata, which held the water and kept the surface-soil in a sodden state. In many places it was found that the shale had been broken up for a considerable depth by the action of the slip, the water having found its way into the pipe-clay veins. When charged with water the soil above the shale had the consistency of porridge, and would not carry its own weight, but when dry it set very hard, and required a pick to shift it.

The remedial works were carried out as follows:—An open cut, 4 feet 6 inches wide, was made, starting from the edge of the cliff. The shale was cut into a succession of steps to give a good footing for the rubble stone with which the drains were eventually filled, a channel sufficiently wide to let in a 12-inch earthenware pipe being cut in the centre, so that no lodgment of water could take place at the different steps. When a length of about 30 feet of cut had been opened out and securely timbered, the pipes with open joints were carefully laid, and the cut filled up with hand-packed stone to within 3 feet of the surface, small fascines of brushwood being laid between the soil and the stone, and fascines laid on the top of the stone, selected soil being then filled in over the drains to surface-level. This process was repeated until the foot of the embankment was reached, after which the cuts were continued as drives under the embankment, the whole being filled with stones and fascines as before. In all eight cuts were made, five were let through the bank and ended in shafts at the high side, which were filled to within 3 feet of the surface with rubble stone, and finished off with fascines and a 2-foot layer of puddle to keep the surface-water out; two cuts were taken nearly to the centre of the embankment and finished with a dead end; the other two were carried to the foot of the embankment only. Large quantities of water were struck as the cuts advanced, but it soon ran out, and at the completion of the work there was only a very small stream running from each of the pipes over the cliff. By the end of 1889 a good crop of couch grass had grown over the work. All the timber, except that in the drives, was drawn.

The work was put to a serious test in the beginning of 1890. In Sydney the rainfall from the 1st of January to the 9th of May amounted to 48½ inches, and it was believed that this was exceeded at Stanwell Park, near the site of the bank. Not the slightest slip took place in the embankment, and the only effect of the rains was a very slight movement between drives Nos. 5 and 6 at the edge of the cliff, not sufficient in any way to affect the stability of the line.

F. G. D.

Consolidated Rail-Joints on the Eastern Railway of France.

By — MÜNTZ.

(Revue Générale des Chemins de fer, August 1890, p. 87.)

The Vignoles, or flange-foot rail alone is laid on this railway. The joints are made with suspended or overhung fish-plates, between two transverse sleepers, placed 24 inches apart from centre to centre. For many years the fished joint was directly supported on a single sleeper; but this system was ultimately abandoned, chiefly because the sleeper was exposed to a rocking movement under the joint, and so loosened the ballast.

The suspended joint proved the better; but the joint was still the weakest part of the rail, and wear and loosening of fastenings continued. To ameliorate, or even to remove this objection, the two joint sleepers were placed closer together, at a reduced distance of 16 inches apart from centre to centre; and, in order to provide clear space for the packing tool, the sleepers were chamfered at their upper inner corners, excepting the portions directly under the rails. The sleepers next to the two joint sleepers were placed at 21½ inches apart between centres. In this way, a combination of four sleepers very closely placed formed a framework well supported.

Two comparative sections of way, 1,000 metres in length, were laid, in the old style, and according to the new system, respectively, and were on trial for a year; at the end of which time they were examined, when it was found that, whilst the older system behaved as usual, in the new way, the joints continued in good order, and the packing under the sleepers was well maintained.

A section of way, comprising 32 kilometres of single line, is in the course of being laid on the new system, for trial.

D. K. C.

The Oppizzi System of Railway-Working by the Utilization of Gravity in Descending Inclines. By P. Verole.

(Il Politecnico, 1890, p. 569.)

The Author, as Secretary to a Special Committee of Engineers appointed by the College of Engineers and Architects of Milan to examine a proposed system of propelling trains by compressed air, submits this report of their proceedings.

The locomotive, in Mr. Oppizzi's system, consists, in its essentials, of a framing on two coupled axles, carrying the accumulators and the air-compressing and expanding apparatus, the function of which is, during the descent, to store the air compressed by the work developed through the simple action of gravity, and to expand and utilize this air to raise the load up a succeeding incline. The accumulators are constructed for a maximum pressure of 30 atmospheres. The apparatus designed for the alternate compression and utilization of the air comprises three cylinders, two of which are of equal diameter, and the third of smaller size; all being placed longitudinally, the small cylinder on the axis of the machine, and the two larger ones over the frame. All three cylinders work (by connecting rods) on to one of the coupled axles. During the descent the cylinders are brought into action by the rotation of the axle, and so accumulate and compress the air; during the ascent the action is that of a compound motor —the central cylinder receiving the air from the accumulators, and passing it at a reduced pressure to the lateral cylinders, whence it is re-emitted. The degree of compression and ex-

pansion, and, consequently, the movement of the train, can be regulated as required.

The points which the committee kept principally in view in their investigations were:—(*a*) possibility of working without detrimental range of temperature in the alternate processes of compression and expansion; (*b*) the weight of train which can be worked in respect of the adhesion of the locomotive; (*c*) secondary arrangements for supplementing working parts if required; and (*d*) the practical possibilities of development of the system, as compared with other existing systems of locomotion. From a theoretical point of view the system was considered to be perfectly sound, and from a practical point, attainable under the usual and necessary limitations and conditions of stability and working. In its economical aspect the system is still involved in some uncertainty. It is evident that the greater the incline the greater is the amount of useful effect developed in the locomotive. This effect is insignificant on the slight gradients of ordinary railway lines; in fact, it is not practically appreciable on an inclination flatter than 1 in 20. Again, in descending an incline, the whole of the mechanical work is not available for increasing the pressure in the accumulators, part being absorbed in the resistance of the vehicles and part developed as heat; the latter being lost in part or altogether—especially in winter—if not immediately utilized in the ascent. The economic aspect depends essentially upon local conditions — gradients, curves, extent of traffic, and so on. The greatest advantage would be in mountain railways, and in gradients through long tunnels where the ventilation is deficient, and where it is especially desirable to do away with the products of combustion.

P. W. B.

New Passenger-Station at Bremen.

(Deutsche Bauzeitung, 1890, p. 381.)

This station, recently erected from the designs of Professor Hubert Stier, was opened for traffic last autumn, and the Paper is illustrated by a small scale plan and elevation of the building, and views from photographs of the interior of the main hall and state saloon.

The idea of the removal of the sites and bringing together under one roof the former existing stations of the Hanover Railway and of the Venlo-Hamburg Railway was first entertained at the time of the taking under State control these and the other lines of the Cologne-Minden Railway Company. Both the lines in question come together at the crossing of the Schwachhaeuser Road, and it was originally proposed to erect the new station near that point; but various considerations led to the final choice of a site fronting the old Heerden Thor in the Altstadt. The works were

commenced in October, 1886; the station arrangement being at such a level as to allow of the streets in the vicinity, formerly crossed on the level, being bridged over.

In the central portion of the building is a large hall 105 feet by 120 feet, with a height of 78 feet, in the middle of which are the ticket-offices, the approach from the street being by four double doorways. From this hall lead four subways, the two middle ones being for the conveyance of luggage to the platforms, and the outer ones for the passengers. On either side are doors giving access to the first- and second-class waiting-room on the one hand, and to the third- and fourth-class waiting-rooms on the other, which, together with the various offices, company's servants' quarters, restaurant and kitchen, form symmetrical wings on each side of the main shed. The main station shed at the back of the above described block of buildings is 646 feet long, 193 feet 6 inches wide, and 98 feet 6 inches high to the ridge. The station arrangement comprises six lines of rails and two main platforms. The roof, of wrought-iron, is constructed on the Schwedler system, similar to that of the Frankfort station, where, however, the span is only 180 feet 6 inches. At the ends of the shed are at each corner massive towers of solid masonry to assist in resisting wind-pressure. The shed is shut in and lit by low-reaching ornamental glass gable-screens, and by side-lights and a central sky-light.

Particulars are given of the various kinds of masonry and stone used in the construction, and of the ornamental groups of statuary, as also of the decorative work in the State reception-apartment.

D. G.

The New Central Railway-Station at Lisbon.

By Emile Pitsch.

(Le Génie Civil, vol. xvii., 1890, pp. 289–323. 2 Plates, 17 Figs.)

The system of Portuguese railways, which has been considerably extended of late, has still a certain number of single lines, the principal being that made thirty years ago from Oporto to Lisbon. A second line goes to Figueira-da-Foz, a branch leaving the main line at Entrocamento goes to Madrid *viâ* Caceres, to the north of Spain by the Beira-Baixa, and to the south of Spain *viâ* Badajoz. A branch line of the Lisbon-Figueira railway goes to Cintra, and a double line to the seaside resorts of Estoril and Cascaes. All these lines came into two termini at Lisbon, one in the Santa-Appolonia quarter at the east end of the city, and the other at the west end, which latter is very remote from the centre of urban life. The necessity of bringing all the lines to a common terminus led the company to draw up plans in 1887 for a central station in the Dom Pedro square, and these are now carried out. The city being built on seven hills, the ground to be traversed was exceedingly difficult. The plan shows that the different lines of the system as

well as a suburban line, 4½ miles long, join outside the city in a station used for making up trains, whence they extend by a double line to the central station. This trunk line passes underground for 2,840 yards up an incline of 1 in 100. The station itself is 455 yards long to the beginning of the incline, although only 234 yards of it is open to the sky, the points being 136 yards inside the tunnel. This construction was rendered necessary by local considerations, and the high price of land. The station has nine parallel lines in groups of two, three, and four, the first two lines are joined by means of a hand-traverser. The group of three is served by a hydraulic traverser, capable of moving locomotives of 65 tons. The group of four lines is served by four turntables worked by a hydraulic capstan. The three groups of lines are separated by platforms from 4 to 9 yards wide. A siding runs to a locomotive shed for two locomotives supplied with a turntable 14 yards in diameter worked by a hydraulic capstan. The engine-house, containing the machinery for working the hydraulic lifts and hydraulic capstans and traversers, is behind the locomotive-shed, and contains four boilers of 30 HP., one force-pump of 25 HP., and an accumulator of 100 tons. The high-pressure pipes are laid in culverts under the platforms covered with stone slabs, and chequered plates for inspection at intervals. The roof is 144 yards long, and covers a surface of 9,570 square yards; the trains are under cover for a minimum length of 110 yards.

The signal-box at the end of the tunnel contains thirty-eight locking-levers. The station building consists of two blocks, two storeys high, making an angle of 85° with one another, so as to use old walls of great solidity. The principal front is 51 yards wide, and has six exits 9 feet wide, and two exits 13 feet wide. The front of the side building faces a large paved square of 2,630 square yards in extent for the arrival of vehicles; but this is at present in communication with a side street with a gradient of 15 per cent., which is to be replaced by a zigzag road with an incline of 8 per cent. to afford easy communication between the lower part of the town and the platform. The ground floor of the principal building is fitted with two Edoux passenger lifts, and also hoists for luggage. The Author then enters into full details of the arrangement of the buildings, and proceeds to describe the tunnel, which consists of a semicircular arch 26 feet wide, built of bricks 2 feet thick, carried on abutments 6·5 feet high, built of ashlar, giving a total height of 19·7 feet under the keystone. The sidings have made it necessary to enlarge the width for a distance of 50 yards, and it increases until it is 36 feet wide at a distance of 27 yards from the end, and as the height remains the same the section becomes elliptical; the tunnel then bifurcates and each portion becomes circular, giving at first a width of 16·6 feet to each arch, and ultimately two arches of the same size as the original tunnel. Above the double arch part passes the cable tram which connects the upper to the lower parts of the city, and the thickness of masonry between the two is very

small. The general lie of the strata cut is that of an arch with its top towards the north-west end, where the strata are much inclined, while they become much more level towards the south-east. The oldest beds found in the tunnel consisted of limestone alternating with clay. These strata were pierced for a length of more than 1,300 yards, and the normal thickness of the beds was about 49 yards; this is followed by white limestone, which was easily pierced, and hard clay. Basalt was found and the tertiary system marl, sandy limestone, and alluvial deposits were passed through. The land was in general fairly solid; the method of tunnelling was that known as sectional. The vault was built first and the buttress walls put in afterwards. In the whole length six shafts were sunk, of which two were placed at the ends so that the tunnel might be entered without waiting for the cutting of the entrance portions. The tunnel was begun on June 2, 1887, and finished on February 25, 1889. The unstable nature of the ground upon which the platform and station building is placed have rendered extra precautions necessary. Pits were sunk to a depth below that which the foundations were to be laid and framed with timber; the wall was then built inside these pits, and only when perfectly solid was the intervening space cleared.

The large hall has a total width of 198 feet, and is covered by a single roof, resting on the outside walls and upon two rows of columns at a distance of 74 feet apart, the width between columns and walls being 62 feet. The mean length is 144 yards, so that the area covered is 9,520 square yards. The main girders are spaced 25 feet apart, and are of the trellis pattern. Details are given as to the mode of building the different girders. The roof is of corrugated iron. The erection was carried out by means of sheers 82 feet high, made of timber, 8 inches square, with seven cross-pieces bolted on; steel chains were used worked by a hand-crab. Messrs. Baume and Marpent, the contractors, carried out the work in three months and a half.

There are two passenger lifts of the Edoux type, which have a total rise of 46 feet with an intermediate stop at the first floor. The upward pressure upon each is 6,000 lbs., and with the weight of the lift itself and the piston, the total amount to be raised is 8,360 lbs. The cylinder is of steel plate $\frac{1}{4}$ inch thick, and the separate portions of which it consists are fixed together by screwed couplings. The chamber of the lift is 10·8 feet long by 7·87 feet wide; the water pressure is 720 lbs., which has rendered balance weights unnecessary.

The baggage lifts are worked by means of pulley blocks without a pit; the hydraulic cylinder is fixed vertically alongside the lift, and has a piston 7 inches diameter, working in guides; this has a stroke one-half that of the lifts, and actuates it by means of steel wire-ropes. Each of these lifts can raise a weight of 7,000 lbs., or a total, including the weight of the lift, of 14,750 lbs.

The traverser carriage for locomotives is capable of moving a locomotive and tender weighing 65 tons on to another parallel line.

The course is limited to 12 feet in either direction; but by means of different tracks on the carriage, a locomotive can be moved from the extreme line at one side to the most distant at the other. The carriage is worked by two hydraulic cylinders supplied with plungers, 9 inches diameter with 4·1 feet stroke, which pull upon chains which pass round grooved pulleys and are fastened at the end to the carriage. The hydraulic capstans are of two sizes, and are worked by three cylinders each.

The motive power is supplied by a steam pump of 25 HP., which draws the water from a reservoir. Four Babcock and Wilcox boilers of 30 HP. each supply the steam; two are in use, and two in reserve.

Particulars of the amount of water required for the various purposes are given, and it appears that the works of the new station are completed for the district trains, but that the main lines are not yet quite in working order.

E. R. D.

Hygienic Requirements in Railway-Carriages. By — Pfuetzner.

(Der Civilingenieur, 1890, p. 312.)

This was a Paper read before the Dresden Society of Engineers and Architects, and referred more particularly to the regulations in use for the comfort and health of passengers on the Prussian State Railways. Carriages with iron or steel underframes are noisy, and wooden frames are in this respect preferable. Spoke-wheels are less noisy than solid disk wheels, but produce dust. The amount of air-space in the compartments required per passenger is 68, 46, and 30 cubic feet for first-, second- and third-class carriages respectively. The average percentage of passengers being, however, only 24·6 per cent. of the available seats, the amount of air-space actually provided is approximately four times as great as indicated by the above figures. The amount of ventilation required in order to limit the percentage of carbonic acid in the air of a railway compartment to $\frac{1}{10}$ per cent. varies between 750 and 1,360 cubic feet per hour per passenger, and the Author considers it hardly possible to obtain so vigorous a ventilation without producing draughts. As regards heating of railway carriages, he objects to stoves on account of danger, and prefers steam-pipes, which should not be put under the seats, but below the floor.

G. K.

On the Prediction of Floods in the Central Loire.

By — Mazoyer.

(Annales des Ponts et Chaussées, October, 1890, p. 441.)

The floods of the Upper Loire were studied by Engineer-in-Chief Jollois (Annales, 1881), who established four types of floods, and gave Tables permitting a prediction of the height of flood at a given place in terms of the maximum height at a point up-stream, and the state of the affluents from that point to the point considered. Some similar observations have been made in the second section of the Loire. Here there are three types only of flood, due:—(1) to floods in the Upper Loire and the affluents near the Cevennes; (2) to floods in the affluents between Digoin and Nevers; (3) to simultaneous floods in both these sources. In the prevision of floods in the Central Loire three districts must be distinguished:—(1) the part between Digoin and Bec d'Allier; (2) the confluence of the Loire and Allier at the latter point; (3) the part from Bec d'Allier to Briare.

In the first district the floods follow a law identical with that found by Jollois for the Upper Loire. When the affluents supply little and the flood is due to the Upper Loire, the height of flood above summer level diminishes from Digoin to Nevers; on the contrary if the affluents discharge much at the time of a flood in the Upper Loire, the height of flood above summer level is nearly constant. To establish previsions between Digoin and Nevers it is necessary to seek the empirical law connecting the maximum up-stream, the state of the affluents, and the maximum down-stream.

Next, observation shows that the maximum at Bec d'Allier depends both on the maximum at Nevers or Decize (on the Loire), and at Moulin (on the Allier).

Between Bec d'Allier and Briare the Loire receives no important affluent, and much of the basin is permeable. Consequently the floods are little influenced by affluents or by local rain. The maximum of floods depends only on the maximum at Bec d'Allier.

The search for an empirical law has been directed by graphic processes. For the first two districts a function of the form—

$$Z = f(x, y)$$

has to be found, which may be considered as the equation to a surface; y is the maximum at Digoin, x the state of the affluents, Z the maximum down-stream to be determined. Five stations are chosen on the principal affluents, and the height of flood at these stations is multiplied by a coefficient proportional to the area of their basins. Taking the sum of these data, a quantity E can be calculated, which represents the state of the affluents at any given moment, above a point where the maximum height of flood is to be predicted.

Suppose the case that a formula is required for predicting floods at Nevers. From observations one plots vertically values of y, the heights of flood at Digoin, and horizontally values of x the corresponding values of E which represent the condition of the affluents. At the point, the co-ordinates of which are x and y, a vertical is taken representing the height Z of the corresponding flood at Nevers. It is easy by interpolation to find a locus for which Z is constant and has any assumed value. Thus curves are obtained which are the projections of contours of the function $Z = f(x, y)$ relating to the station Nevers. Such curves are given for four stations. Formulas may be found from these. For instance, if N is the maximum at Nevers, D the maximum at Digoin, and E the state of affluents.

Height at Digoin :—

0–3 metres	$N = 0 \cdot 48\,D + 0 \cdot 06\ E.$
3–4 „	$N = 0 \cdot 53\,D + 0 \cdot 054\,E$
4–5 „	$N = 0 \cdot 58\,D + 0 \cdot 054\,E.$
Above 5 „	$N = 0 \cdot 64\,D + 0 \cdot 050\,E.$

A Table of errors of predictions is given to indicate the amount of accuracy attained. The velocity of propagation of the floods from Digoin to Nevers is very variable, being greater when the flood is chiefly due to the affluents. The mean velocity is 3·56 kilometres per hour. The maximum height at Nevers can be predicted from the maximum at Digoin more than half a day in advance. But as this is an insufficient warning, a preliminary prediction can be made by calculating the maximum at Digoin from the maximum at Roanne, which gives at least an additional eleven hours. The Author then discusses the similar rules established for the confluence at Bec d'Allier.

For the part of the river below Bec d'Allier, when the height at this place is observed or predicted, the proceeding is more simple. Plot the heights x at Bec d'Allier as ordinates, the heights y at the station considered as abcissas. Then every flood is defined by the points $x\ y$. The lines obtained are nearly straight. Formulas for five stations are given.

W. C. U.

The Improvement of the Adige at Legnago.

By Pace Mutinelli and Giovanni Barnabei.

(Giornale del Genio Civile, 1890, p. 217.)

The Technical Commission, appointed in 1882 to consider the general improvement of the rivers in the Venetian province, and to carry out the necessary operations, has recently completed an important work in widening the channel of the Adige at Legnago, where, in traversing the area included within the fortifications, the bed was considerably restricted, and serious floods were

frequently occasioned. Both above and below the town, the river has an average width of 985 feet; but at the point referred to, where it was crossed by the old bridge, the width of the waterway was reduced to 370 feet.

It was decided to remove part of the fortifications, and to demolish a number of buildings on the left bank, to enable the channel to be excavated to a minimum width of 520 feet, the old bridge being removed, and replaced by another structure at a point lower down the river. To form the new channel it was necessary to construct new dykes 2,665 feet in length, to strengthen a considerable length of the old dykes, and to build 1,128 feet of retaining walls. The summit-level of the dykes is 15 feet 6 inches above mean water-level, the width of the same being 26 feet 3 inches, the back slope $1\frac{1}{2}$ to 1, and the front slope 2 to 1; the latter faced with limestone pitching 14 inches in thickness, with a benching 5 feet in width at low-water level, and the upper part turfed.

The walls are built in brickwork in hydraulic mortar, with a face-batter of 1 in 10, and vertical set-offs at the back, on concrete foundations carried down to an average depth of 16 feet 6 inches on the left bank, and 13 feet on the right bank. The concrete is composed of Bergamo (hydraulic) cement, Adige sand, and sifted gravel. The works were severely tried by a flood in October 1889, but were successfully completed, and have effected a reduction of 2 feet in the water-level.

The new bridge has a total length of 523 feet 8 inches, and consists of two side spans of 88 feet 3 inches each, and a continuous girder 347 feet 2 inches long, in two side openings of 108 feet 9 inches each, and one central opening of 129 feet 8 inches. The two main lattice girders are 10 feet $4\frac{1}{2}$ inches deep, spaced 20 feet 4 inches centre to centre, carrying the roadway; with a footway 5 feet 3 inches wide on cantilevers on each side, giving a total width of 30 feet 10 inches. The underside of the bottom flange is 18 feet 9 inches above mean water-level, and the surface of the roadway 22 feet 9 inches. The abutments and piers are in masonry, the foundations being sunk to depths varying from 54 feet to 60 feet. This work was accomplished by compressed air, with two direct-acting compressors of 30 and 40 HP. respectively. The cost of construction of the bridge and approaches was £36,500. P. W. B.

The Engineering Works Connected with the Regulation of the Rhine at St. Gall. By J. Wey.

(Schweizerische Bauzeitung, 1890, vol. xv. p. 19.)

The Author traces, as far as records permit, the progress from the earliest times of the protective works constructed for the regulation of the Rhine, and enumerates the most notable floods

that have occurred in the past, dividing the subject into three periods, viz., from the year 1000 to 1800, from 1800 to 1860, and from 1860 to the present time.

Little is known of the first period prior to 1343, the date of the first authentically recorded flood, and in the chronicles of the 15th century mention is made of the construction of embankments and attempts to keep the stream within bounds; but time proved, with the increasing frequency of inundations, that these works tended rather to make matters worse than otherwise. In 1790 the engineer Römer was requested by the authorities to report upon the nature of the protective works that should be undertaken on this section of the Rhine, and he recommended that the distance apart of the river-banks should be fixed at 886 feet. At that time also was first considered the question of the construction of a cut between Brugg and Fussach, thereby shortening the river-course and giving it a more direct outlet into the Lake of Constance, in place of embanking the natural course of the stream between those points. No definite conclusion, however, was arrived at. In the second period, viz., from 1800 to 1860, the construction of continuous lengths of training-walls in place of isolated works was progressed with, and the creation of cultivatable land by warping attempted, but without following any definite comprehensive plan; one of the effects, however, being to raise the level of the river-bed. The lateral distance apart of the training-walls varied from 360 to 1,640 feet, and the land embankments (*Binnendaemme*) were at very irregular lateral distances, so that the flood-water area varied from 820 to 3,280 feet in width.

The first serious attempt at dealing with the difficulty in a thorough manner was due to the engineer Hartmann, in 1836, who instituted investigations for ascertaining the proper lateral distances apart at which the training works and embankments should be constructed, and with this view he divided the length between Tardisbrück and the Lake of Constance into one hundred and twenty-five sections, and erecting distance-posts and gauging-stations, which have been in use from that time forward and formed the bases of later observations. At each of these stations cross-sections of the river-bed were taken, and from these were plotted the first longitudinal section that had been made, and the first step accomplished for ascertaining the data necessary for dealing with the question in a practical manner.

The various inundations which occurred during the second period and their consequences are described. In the first half of the present century, seven floods of importance are mentioned, causing the destruction of embankments and the inundation of large tracts of country. These floods appear to have become more and more serious, and may be accounted for by the increase during centuries of ill-adapted training-works, &c., and also by the gradual dis-foresting of the district, and consequent more rapid drainage and carriage of surface soil into the river, the bed of

the stream thereby being raised and the outfall of the lateral smaller streams consequently becoming choked; and the Author expresses the opinion that re-foresting to a great extent must be an essential part hereafter in dealing with the question of the prevention of floods, in the district in question. In 1855 the works recommended by Hartmann and their cost were as follows:—

	£	Francs.
Correction of the Rhine from the Swiss frontier to Monstein	112,000	(2,800,000)
New cut from Brugg, passing to the right of Fussach	84,000	(2,100,000)
Or, say	200,000	(5,000,000)

This estimate, upon a revision of the scheme by Hartmann in 1860, was increased to £340,000 (8,500,000 francs). In the third period, viz., from 1860 to the present time, the works carried out have been principally of the nature of parallel training-walls, designed with a view to, as far as possible, straightening the course and conducing to a uniform flow of the stream, so as to prevent the deposition of silt and ensure the conveyance of the latter far out into the lake. Having regard to existing works, the breadth recommended by Hartmann for the river-channel was as follows—viz., from Tardisbrueke to Schollberge (Truebbach), 380 feet; in Werdenberg, 400 feet; and along the Austrian frontier, from 450 to 480 feet. As with these breadths, at low-water, the stream would only occupy a portion of the enclosed space, Hartmann proposed a low-water channel of 240 feet in breadth; but it was considered that the formation of three different beds suitable to the conditions of low, mean, and high-water would be too complicated. The amounts of flow per second, estimated by Hartmann, were as follows—viz., at low-water, 2,500 cubic feet, and at high-water, 70,000 cubic feet. Further observations and measurements, since made, have given the following as the amounts per second, in place of the foregoing, viz.:—

——	At Ragaz.	At Rheineck.
	Cubic Feet.	Cubic Feet.
At low-water	742	2,119
At time of melting of the snows . . .	21,189	28,253
Extraordinary flood	105,948	134,200

The carrying out of Hartmann's project was commenced in 1860, but in 1868 an inundation occurred, laying vast tracts of land under water, extending from Ragaz to Monstein. This failure may be partly accounted for by the fact that, in general construction, the original project had been gradually departed from, although contrary to the intention of Hartmann, who at this time was advanced in years and in ill-health; and the training-works,

instead of being kept at such a level as to allow of their being topped in times of flood, had been carried up to a much higher level, and that they were made up of ballast and pitched, on the stream side only, with stone. This modification was chiefly due to the efforts of the inhabitants of the valley, who preferred that the training-walls should be raised to such a height as they imagined would do away with the necessity for the outer land-embankments, which latter would have to be maintained at their expense.

In 1871 an inundation again occurred, laying the whole valley from Sevelen to Monstein under water, and created even greater consternation than that of 1868, owing to the great outlay upon protection works made in the interval. The result of a further inquiry instituted by the Bundesrath was that on the section between Tardisbrueck and Oberriet the in-submersible training-walls should be made continuous instead of only partially so, and that the works between Oberriet and Monstein should be on the double-line system; that the high training-walls in the first-mentioned section and the land embankments in the second section, should be carried up to a height of 2 feet, and in concave curves to 3 feet above the average level of high-water. This necessitated ascertaining precisely what the height of flood-water above low-water would be on the various sections, and resulted in the opinion that instead of 10 feet 9 inches to 11 feet 9 inches, as formerly estimated, the embankments should be raised to a height of 16 feet 6 inches to 19 feet 6 inches above low-water, necessitating an increase in the estimated cost of the works of £260,000, making a total sum of £600,000.

The Paper is illustrated by a map of the district, extending from Oberriet to Lake Constance, showing the course of the various proposed cuts; also a longitudinal section is given of the bed of the Rhine and of the embankment-crown between Monttingen and the lake, and a cross-section of the river at Buchs; also a cross-section of the proposed Drepoldsauer Cut, which it is advised should supplement the cut between Brugg and Fussach.

D. G.

The Regulation of the River Wien from a Sanitary Point of View. By J. N. Moraeth.

(Wochenschrift des oesterreichischen Ingenieur- und Architekten-Vereines, 1890, p. 180.)

In this Paper the Author records his emphatic protest against the proposed arching over of the river, and refers to the evil results of a similar treatment of the Gratz brook some years ago, where, owing to the imperfect construction of the openings for the discharge of rain water, the air was charged with mephitic gases, which even entered direct into the houses through the waste pipes

from the kitchens. As a good example to be followed, he mentions the arrangements adopted in Amsterdam and other cities in Holland where proper sanitary measures are taken, and the sewers are fitted with efficient traps which prevent the escape of gas, the sewage being pumped or baled out of the reservoirs during the night, and conveyed in closed vessels to factories built expressly for working up the sludge; consequently no offensive smell affects the neighbourhood. Similar provision, the Author states, should be made in Vienna; the River Wien would then be free from noxious odours, and would not only serve for navigation, but the water from the Danube could be pumped up to a height to serve not only for the use of houses and factories, but also to flush the drains, and thus relieve the Hochquelle supply.

In support of his protest against arching over the river, he quotes from a pamphlet by Engineer Willfort entitled "The question of the regulation of the River Wien," in which it is stated that if such a length of the river as is proposed be arched over, the mephitic gases generated within would discharge either in the city park or at Schonbruenn, according to the direction of the wind, and thus affect the health of the city. The Author's proposals embrace also the deepening of the river, by which means the torrent-like floods would be the more easily discharged into the Danube, and navigation up and down stream is carried out by attaching the vessels to an endless wire rope worked by the power of the water itself. A railway along the banks forms part of the scheme, which will be connected with Krauss's steam tramway, and the tall shaft or chimney at the terminus would serve to draw the injurious gases out of the sewers, whence they would be consumed according to Friedmann's system, and thus the complete sanitation of the city would be accomplished by a thorough flushing of the sewers under high pressure, and also by their efficient ventilation. The cost of the project, exclusive of the railway, is given at £875,000.

W. H. E.

The Connection of Rome with the Sea by a Navigable Canal.

By Professor A. OELWEIN.

(Wochenschrift des oesterreichischen Ingenieur- und Architekten-Vereines, 1890, p. 253.)

The project described in this Paper is by Mr. Oberholtzer, an Italian engineer of German origin, and is now being seriously entertained in commercial and shipping circles, and by the Italian Government itself.

After giving an exhaustive account of the various projects,[1] which have been prepared from ancient times to the present

[1] Minutes of Proceedings Inst. C.E., vol. lxxxii. pp. 2-19.

of the European Powers has compelled the increase not only of her army, but of her navy also, to defend her long line of coast, and especially the capital, Rome. Hence the canal is to be deep enough to admit the largest ironclads, and the construction of three forts is included in the scheme, viz., at Mezzo-Cammino, near Castel Fusano, and at the sea-mouth of the canal. Rome, then, it is stated, would be strategically of greater importance and a stronger port than Spezzia, or the fortified roadstead of Maddalena or even Genoa.

The depth of the canal will be 32·8 feet. From its mouth it will be carried through the Ostian marshes to Castel Fusano, and about a half mile beyond this the first basin will be constructed; thence it follows the Polocco road along the Dragoniello hill, where a second basin will be built. From this point the trace is parallel to the Ostian road and terminates in the plain of the "due Torri," south west of the church of San Paolo. The Canal is about 12 miles long, and its mouth will be extended between stone embankments into the sea, until a depth of 36 feet of water is reached. The port or harbour of Rome is to consist of a rectangular basin 1,500 yards long and 650 yards wide; on the north-west side of which is a semicircular basin 490 yards in diameter and furnished with docks. The cost is estimated at £3,500,000.

Owing to the horizontal or level trace of the canal the bed of the Tiber at Rome lies much higher than the surface of the water in the basin. This difference of level will give a head of water which can be successfully utilized for industrial purposes.

The excavated material from the canal will serve to fill up the deadly fever-stricken marshes between Ostia and Castel Fusano, and ultimately bring them under cultivation.

A map of the country between Rome and the sea, together with plan and cross section of the canal, accompany the Paper.

W. H. E.

The Harbour-Works of Marianopol and Novorossisk.

By — Hermann, Ingenieur des Ponts et Chaussées.

(Annales des Ponts et Chaussées, August 1890, p. 239.)

The Russian Government has of recent years laid out large sums of money on improvements connected with the navigation of the Black Sea and in the construction of new harbours. Owing to certain hindrances to navigation in the Gulf of Taganrog, which has hitherto been the chief port in the Sea of Azoff at the mouth of the River Don, it was decided in November, 1884, to create a new

harbour at the town of Marianopol, 65 miles to the west of Taganrog and just outside the gulf, since its position near to the extensive and recently-opened coal-field of Donetz, with which it is connected by railway, seems to ensure its soon becoming the most important commercial depôt in the Sea of Azoff. The cost of the harbour works is estimated at £450,000. They were commenced in the summer of 1886, and are to be completed by March, 1891. The works comprise, first, a deep-water harbour; and secondly, an inner basin between the small River Kalmious and the town, to serve as a place of storage during the winter months, when access to the Sea of Azoff is closed by ice.

The site chosen for the harbour is to the west of the town, at a point where there is deep water near to the shore, and where an opening in the adjacent hills will allow of the works being extended inland and surrounded by extensive landing-quays, with warehouses and a railway-station. The outer harbour, with an entrance 140 yards wide, is being formed by two converging sea-walls, starting from a sandy beach, enclosing 346 acres, with 14 feet 6 inches depth of water throughout, and built with foundations to allow of the depth being ultimately increased to 18 feet. The western wall is continuous and 1,760 yards in length; the eastern is altogether 2,077 yards long; but at the distance of 540 yards from the shore end it is interrupted by an opening 70 yards in length, protected by a separate pier, to give admission to the harbour at that point to coasting and other small vessels.

The construction of the sea-walls is on a German plan, which has already been carried out in the Baltic at Pillau, Neufahrwassen and Ruegelwassermuenden. Timber being very abundant, a cofferdam is first built, with a double line of piles, held in position by cross-pieces. The water in the Sea of Azoff contains very little salt (its specific gravity is 1·00097), and timber is very slightly affected by it. The cofferdam is filled in with rough blocks of limestone, which are allowed to settle during three years, after which all stones which remain above the water-level are removed. The sides of the wooden cofferdam are then strongly tied together with wrought-iron rods, and a narrower superstructure built upon it in masonry, surmounted by a course of ashlar. The deepening of the harbour has involved dredging more than 1,000,000 cubic yards of sand and mud, and the cost of the sea-walls has been at the rate of £62 per lineal yard. The quay-walls are constructed on a foundation of rough limestone, also within a wooden cofferdam.

The inner basin, on the right bank of the Kalmious River, is 256 yards long by 93 yards wide, and the depth of water is 9 feet. A stone embankment protects it on the side of the river from the ice-floods, which are dangerous in winter.

Novorossisk is a port on the eastern shore of the Black Sea, at a point where a spur of the Caucasian mountains encircles a bay, from whence, in 1888, a branch railway, 168 miles in length, was

opened, which connects this town with the main line of railway running from Rostov, on the Don, to Vladikaukas. The new harbour comprises a quay-wall 1,265 yards in length, faced by a curved breakwater 932 yards long, both constructed of artificial blocks of concrete laid upon a broad bed of large broken stone, and the only peculiarity of the work consists in the automatic method of preparing the material for these blocks. They vary in length from 7 to 14 feet, and in depth from 6 feet 6 inches to 7 feet, and are made of a mixture of ten parts of pebbles and four of mortar, the latter being composed of three parts of sand to one of cement. These materials are brought to the top of a building of three floors, constructed against the side of a hill, and are screened and sifted while falling to the second floor. The sand and cement here fall in correct proportion into a puddling-mill and are churned together with water, the mortar so produced falling thence to the floor below into boxes of a measured size, with false bottoms of wrought-iron. The pebbles fall into similar boxes of the same size, and by an automatic arrangement the wrought-iron bottoms are then lowered at regular intervals, dropping the contents of the boxes into a revolving chamber below, the measure of pebbles falling ten times and the mortar four times per minute. This ensures the concrete being always composed of exactly the right proportion of each material. With two sets of apparatus at work, 145 cubic metres of concrete are made per day. From this chamber the concrete is conveyed in trucks, worked by an endless chain, to which they are successively hooked, to the spot where the blocks are made.

The works were commenced in the summer of 1888, and are to be completed in 1892, their estimated cost being £356,500.

O. C. D. R.

The Campen Lighthouse and the Illumination of the Lower Ems.

By C. Riensberg.

(Zeitschrift des Vereines deutscher Ingenieure, 1890, p. 1193.)

Emden, formerly a Hanoverian port, was, until within the last few years, so far neglected, that the harbour was entirely silted up; and as a necessary preliminary to the revival of its commercial importance, it was necessary for the Prussian Government to enclose and dredge the harbour to an average depth of 23 feet of water, and then to improve and regulate the channel of the Ems. These works being completed, it then remained to render secure the navigation of the estuary, and this object has now been carried out by the construction of six lighthouses between Emden and the open sea, viz.:—

—	Height.	Light visible.
	Feet.	Nautical Miles.
1. Borkum, 2nd class light	105	16
2. Rottum, 3rd „	82	14·7
3. Campen, 1st „	216	20
4. Pilsum, 4th „	49	12·4
5. Watum, 4th „	66	13·6
6. Delfzyl, 4th „	49	12·4

Each of these lights throws a beam along a certain portion of the navigable channel, and navigation is therefore controlled by the successive intersections of these rays. Campen lights two channels, Watum two, and Delfzyl three, and the others one each. A vessel entering inwards, for instance, passing the Rottum light, follows the path of the Borkum light, until this is intersected by the Campen first beam; follows this till the Pilsum light becomes visible; steers towards this till its course is diverted by the second beam from the Campen tower, and so forward to Watum and Delfzyl. Each tower shows a fixed white light on the channel, but the position is indicated to vessels approaching from the seaward side by an even number of flashes per minute of the same light, and from the Emden side by an odd number of flashes. These flashes are given by Otter's shutter apparatus, set by clockwork to the required rate of working.

The most important of these structures is the lighthouse near Campen. Various designs were prepared for this tower, the plan eventually adopted being a central shaft (containing a lift and spiral staircase, leading to the keeper's rooms and the lantern), and three wrought-iron piers, all connected by horizontal and diagonal bracing. The minimum of surface is thus exposed, and the strains are much simplified and concentrated by the adoption of the triangular arrangement of the piers as compared with a larger number of columns.

The foundations are carried through soft alluvial soil to a depth of about 40 feet, where firm hard soil is reached. The diameter of the pier foundations is 19 feet, and that for the shaft 14 feet; the outer facing is of masonry, with concrete filling. Each pier is held by an anchor-plate built in at a depth of 26 feet 3 inches, with four bolts 4 inches in diameter, which are calculated for a collective strain of 135 tons in the severest hurricane. In designing the piers, the chief consideration was the permanent accessibility of every part of the structure, careful maintenance being essential where the surface of the metal is constantly acted on by the atmosphere filled with saline particles, and by the spray from the sea itself. Instead of columns, therefore, the piers consist of

gross sectional area at the base being 124 square inches. The piers have a rake of about 1 in 9, the base of each triangular face having a length of 47 feet 6 inches, and the truncated apex 17 feet.

The diagonal bracing consists of two channel-irons riveted together. The central shaft is not rigidly connected with any other part of the structure, but is encircled by stiffeners, to which the bracing is bolted, so that all lateral strains are transmitted to the piers. The internal diameter of the shaft is 8 feet 2½ inches, the central lift—capable of taking any load up to 12 cwt.—is 2 feet 3½ inches in diameter, the staircase being 2 feet 11½ inches wide, and consisting of three hundred and eight steps in twenty-two flights. The total height to the floor of the store-room is 174 feet. Over this is the keeper's living room, and above this the lantern-room, containing the Fresnel electric light apparatus, throwing a beam of 6,500 candle-power. The lantern-room is amply ventilated by seventeen inlets at the floor-level, and by one large central outlet at the apex of the roof, and nine small cowls. The roof is covered with copper plates.

The calculations for the strength of the structure are based upon the extreme assumption that every part will be exposed to the full force of hurricane pressure; and the maximum strains in various parts of the bracing and piers do not exceed 2·6 tons per square inch in compression, and 4·45 tons in tension. The total weight of ironwork, including anchor-bolts and lantern, is nearly 300 tons. The actual erection of the tower was completed in the space of five months.

P. W. B.

On the Yield of Wells sunk in Permeable Soils.

By Fossa Mancini.

(Annales des Ponts et Chaussées, June, 1890, p. 823.)

The subterranean flow of water, which forms the supply of wells, is a matter of such complexity that it will be impossible to interpret its principles analytically except by resorting to purely hypothetical assumptions; but it would be useful to have the means of estimating the supply that could be obtained under given conditions.

With this view the Author takes the case of a river-basin consisting of permeable alluvial soils resting upon a horizontal bed of some impervious material, whose level coincides with the bottom of the river; and he assumes the underground waters to flow towards the river at right angles to the valley line, and to deliver into each lineal unit of the river channel, a certain discharge Q.

According to the experiments of Darcy and Dupuit, the velocity of this percolating current will be proportional to the inclination of the plane of saturation; and it follows that under the given conditions, the surface of saturation will not be a plane but a convex surface, whose section at right angles to the river will be a parabolic curve, the axis of the parabola being coincident with the surface of the impervious bed.

Thus if z denotes the height of saturation above the impervious bed at any distance x from the river, the velocity of flow will be $v = k \frac{d z}{d x}$, in which k is a coefficient depending on the permeability of the soil; while at the same time $Q = \phi z v$, in which ϕ represents the effective percentage of the intersticial spaces in the mass; whence $x = \frac{\phi k}{Q} \cdot \frac{z^2}{2} +$ constant; and putting $h =$ the height of water in the river above the same impervious bed,

$$z = \sqrt{\frac{2 Q}{\phi k} x + h^2}$$

The Author examines the effect of temporary variations in h and in Q, and having deduced the conclusion that the level of saturation will be only affected very slowly by these changes, he goes on to consider what altered currents would be set in operation by sinking a well in the permeable bed of the valley at a distance l from the river, the well being carried down to the level of the impervious bed, and the water kept down by pumping to a height h_o above that level.

The stream-lines, which were originally parallel in plan, will now converge towards the well, a certain number of them being intercepted by it, while others are drawn towards the cone of exhaustion, but pass round it and into the river. In the neighbourhood of the well the stream-lines are nearly radial, and if q is the discharge entering between two radial lines which enclose the small angle θ, there will result at any distance x from the centre of the well, $q = \phi x \theta z v$; and applying again the same formula $v = k \frac{d z}{d x}$, the inclination of the surface of saturation is given by $\frac{d z}{d x} = \frac{q}{\phi k x \theta z}$, whence by integration is obtained for the curved form of a section taken radially through the cone of exhaustion—

$$z^2 = \frac{2 q}{\phi k \theta} \cdot \log_e \frac{x}{R} + h_o^2,$$

in which R is the radius of the well.

If the section is taken in a landward direction, running away from the river, the surface of saturation, commencing at the water-

level in the well, will approximately follow the curve above given for a certain distance, until the stream-lines become sensibly parallel instead of radial, or until the curved surface coincides with the inclination of the original parabolic surface. This takes place at an unknown distance x_o, and to find its value the Author proposes alternative analytical and geometric methods. The following expression is then deduced for the maximum supply entering on the landward side, through the small arc θ, viz.—

$$q_a = \frac{\phi k}{2 R} \cdot \frac{H_o^2 + \frac{2 Q}{\phi k} x_o - h_o^2}{\log_e \frac{x_o}{R}}$$

in which H_o is the original height of the parabolic surface at the well itself, or the natural level of saturation at that point. But on the opposite side of the well, towards the river, the flow entering through the arc θ will be smaller, and, indeed, may sometimes be a negative quantity. Between the well and the river, the surface of saturation will fall in both directions, and its section will have a summit between those points.

If the distance l is great, and the inclination of the original parabolic surface at the well, is small, it may perhaps be assumed that the summit will occur at a distance from the well nearly equal to x_o; and on this hypothesis the minimum flow entering on the lower side is expressed by—

$$q_b = \frac{\phi k}{2 R} \cdot \frac{H_o^2 - \frac{2 Q}{\phi k} x_o - h_o^2}{\log_e \frac{x_o}{R}}$$

Finally, if the difference between q_a and q_b is not too great, the mean value may be taken as applying to the whole circumference, and the total yield will then be—

$$P = \pi \phi k \frac{H_o^2 - h_o^2}{\log_e \frac{x_o}{R}},$$

which is equivalent to—

$$P = \frac{2 \pi Q l}{\log_e \frac{x_o}{R}} \cdot \frac{H_o^2 - h_o^2}{H_o^2 - h^2}$$

The Author describes some experiments that were made on a small scale to test the value of these deductions. A box $1\frac{1}{2}$ metre by 1 metre was divided into three compartments, the central one

being filled with sand, which covered 1 square metre, and which was traversed laterally by a continual percolation of water flowing from a higher to a lower reservoir, the reservoirs being contained in the two extreme compartments which were fitted with apparatus for regulating the head.

In the centre of the sand area was a well in which the water could be kept down to any adjustable level; and to ascertain the level of saturation at different points, a series of small perforated tubes was sunk in the sand in two rows, one longitudinally and the other transversely.

The first experiments were concerned only with the direct flow from one side to the other, and served to determine the value of $\phi\, k$, which was found to be nearly constant under varying heads. The well was then put in operation and worked at different levels, the yield being measured and the curve of the surface of saturation noted in each case.

The observed sections of the cone of exhaustion agreed very well with the logarithmic curve deduced by theory. The actual yield of the well was compared with the quantity given by the above formula after inserting the ascertained value of $\phi\, k$, and was found to be always less than that quantity, the actual discharge ranging from 90 per cent. down to 43 per cent. of the calculated amount.

The deficiency is believed to be partly due to the limited scale of the experiment.

T. C. F.

On Deep-Well Waters Rich in Iron-Compounds, and on the Removal of the Iron from the same. By B. Proskauer.

(Zeitschrift fuer Hygiene, 1890, p. 148.)

The requirements of the sanitarian in respect of the water needed for drinking purposes, are summed up, and the Author points out that compliance with these data points to the adoption either of spring-water, or of water derived from the lower layers of the soil. The dangers connected with the latter source of supply are discussed, and though water of this character is in other respects unobjectionable, it may frequently be so rich in iron as to lead to its total rejection, as was the case at Berlin and Frankfort on the Oder, or it may necessitate the sinking of entirely new wells, as was done at Halle and Leipsic. The characteristics of the iron-laden water of the Berlin district are described, and a table of nineteen analyses by various experimenters is given to show its chemical composition. In the deep-well water, the iron is usually present as ferro-carbonate, held in solution by the free carbonic acid, but a small proportion occurs as ferro-phosphate. Another point worthy of notice is the almost invariable presence of ammonia. Traces of nitric acid were seldom found, and nitrous acid was in all cases absent. Some of the samples tested

contained considerable amounts of chlorine. A characteristic of the well-water of the North German plains is the presence of a notable volume of sulphuretted hydrogen gas; this, however, disappears after a brief exposure to the atmosphere. All the waters tested were rich in carbonic acid gas, while traces only of oxygen gas were occasionally found. The Author mentions that ammonia, sulphuretted hydrogen, and a high percentage of chlorine are found in the waters of sparsely-inhabited, as well as in those of populous districts, and that these substances cannot, therefore, be derived from excrementitious sources. The effects of the exposure of water of the above character to the air are described, a gradual separation and deposition of the iron, owing to combination with oxygen and the formation of insoluble compounds, almost invariably taking place after a shorter or longer period. Tables of analyses are given to show the various conditions under which these changes take place. The difficulties caused by the use of iron waters for town-supplies are set forth, the deposit in the mains and the almost certain growth of crenothrix being those chiefly encountered. It was under these circumstances that the towns already mentioned had to abandon the use of their service-water, and to seek for fresh supplies. It is pointed out that neither the iron salts nor the crenothrix so often found in water of this character are in themselves injurious to health; but that in order to render such supplies capable of being utilized, it is necessary to devise some plan by which the water, directly it is raised to the surface, and before it enters the mains, may be so far freed from iron that no further deposit of iron can take place. The best means of accomplishing this is by effectual and thorough aeration, combined with subsequent filtration.

As an instance of an imperfect and incomplete mode of effecting this object, the Author describes the plan adopted at the Potsdam works, which has resulted in failure. Further attempts to improve the aeration by pumping in large quantities of air (four volumes of air to ten volumes of water), and by admixture with the comparatively pure water of Lake Tegel, both proved unsuccessful. Subsequent experiments upon the water in the form of cascades, combined with filtration, led Mr. Bischoff to express an opinion that it was practicable to so far free waters from iron compounds as to render it possible to utilize the same.

The processes of Mr. Oesten, the chief engineer of the Berlin waterworks, and the various experiments undertaken to test the best mode of aerating the water, are explained by reference to a diagram. The reasons for the ultimate adoption of a rain-producing apparatus, wherein the water falls in fine streams through a space of 2 metres (6 feet 6 inches), and is then passed through a filter at the rate of 1 metre per hour, are set forth. The Author states that the process of filtration can be safely conducted at ten times the speed of ordinary filter-beds employed in the clarification of surface-water.

A plan of estimating the amount of iron present in the water by means of colour determinations with rhodammonium solution, as used by the Author with successful results, is appended.

G. R. R.

High Masonry Dam on the Croton River.

By A. Fteley.

(Report of the Chief Engineer of the Aqueduct Commission, New York, 1890.)

The report contains an account of a series of diamond-drill borings and test-holes driven along the valley, to determine the depth and quality of the underlying rock. Three possible sites for a dam below the present Croton river dam are criticised. One is the site originally selected for the proposed Quaker Bridge dam. The second is a site 1¼ mile above Quaker Bridge, where a dam less costly than that at Quaker Bridge could be built. The third site (No. 2) is one which would permit the construction of an earth dam. The following Table gives some particulars of the estimated size and cost of the dam for each site:—

Location.	Greatest Height.			Length of Dam between Flow-lines.	Storage in Million Gallons.	Cost of Dam.	Cost of Roads, Bridges, &c.	Probable Time of Construction.
	Above River Bed.	Below River Bed.	Total.					
				Feet.		£	£	Years.
Quaker Bridge .	180	91	271	1,402	34,000	810,000	215,000	6
Cornells . . .	159	70	229	1,736	30,000	730,000	215,000	5
No. 2. Masonry	105½	100½	206	995	16,000	490,000	180,000	4
" Earth and Masonry	105½	100½	206	995	16,000	350,000	180,000	3 to 4

The Report then points out the necessity for a large reservoir below the present Croton dam. The present Croton dam is not built in such a manner as a structure should be, on which depends the very life of New York, and the important parts of the new aqueduct system were designed in view of the construction of a high dam on the lower part of the river. The dam originally intended was not begun simultaneously with the aqueduct. Owing to the delay, it became evident the construction of the Quaker Bridge dam would occupy too much time, and that the speedy provision of additional storage was an absolute necessity for the supply of the new aqueduct. Four smaller dams were therefore begun, intercepting the drainage of the upper part of the valley, but there is still need of a reservoir intercepting the drainage of

the lower part. Site No. 2 would permit the construction of a reservoir probably sufficient to supply the demand for the next twenty years. This is considered sufficient, and the construction of a dam on site No. 2 is recommended. With the reservoir so provided, the storage (including the reservoirs now under construction) would amount to 50 billion gallons, or two hundred days' supply of 250 million gallons per day.

W. C. U.

On the Quality of the Water-Supply of Berlin in the Period from April 1886 *to March* 1889. By B. PROSKAUER.

(Zeitschrift fuer Hygiene, 1890, p. 103.)

This is a continuation of previous reports upon the subject by Professor Wolffhuegel, and by the Author in conjunction with Dr. Plagge.[1] The arrangements for the filtration and distribution of the Berlin water have recently been dealt with by Mr. C. Piefke;[2] but since the date of his essay the extensions of the works on Lake Tegel have been completed, and the installation now comprises twenty-one covered filter-beds, with an area of about 50,000 square metres, capable of furnishing a daily supply of 86,400 cubic metres to the high-level reservoirs at Charlottenburg. Tables are given to show the total monthly yield from the two works at Stralau and Lake Tegel for the three years, the combined volumes being 29,967,790 cubic metres for the twelve months ending March, 1887; 30,877,360 for 1888; and 31,620,750 for 1889. The quantities supplied from each of the works on the particular days on which tests were made are also given in separate Tables. The number of blocks of buildings (*Grundstuecke*) supplied with water for the year ending March 31st, 1887, was nineteen thousand one hundred and ninety-three; for 1888, nineteen thousand seven hundred and seventy-five; and for 1889, twenty thousand four hundred and three. The volume of water accounted for in each of the three years was respectively 83·49, 84·36, and 85·55 per cent. of the total supply. The fluctuations in the daily supply are likewise given in a tabulated form as maximal and minimal proportions with yearly averages.

Samples for testing were taken periodically at eleven different named places, so as to comprise specimens of unfiltered and filtered water from each works and service-water from various localities in the town. As in previous years, the water of Lake Tegel in its natural state was superior to that of the Spree as respects colour, clearness, suspended matters, taste and smell. The numbers of bacteria present were again greater in the case of the Spree water

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxviii. p. 519.
[2] *Ibid.*, vol. cii. p. 363.

than in that drawn from Lake Tegel. The maximum number in the Spree water was one hundred and ninety thousand per cubic centimetre, and the minimum eighty-nine. In the case of the Lake Tegel water the maximum was nine thousand one hundred, and the minimum seven germs. Bi-monthly bacteriological tests of both kinds of water are given. On only five occasions in the three years did the number of germs in the unfiltered water of the Spree fall below one thousand in the cubic centimetre. Of the seventy-four samples tested, forty-two contained between one thousand and ten thousand germs, and in twenty-seven the germs exceeded ten thousand per cubic centimetre. In the case of the water from Lake Tegel, on only nine occasions did the number of germs rise above one thousand. In thirteen out of the seventy-four samples there were upwards of three hundred, and in fifty-two samples the germs were under three hundred (in forty of the latter number they even fell below one hundred) in the cubic centimetre. The fluctuations in the number of germs are discussed, and the Author points out that the tendency of the Spree water is to deteriorate, while the lake water has certainly, in the period under review, become more free from micro-organisms. Tables too long for abstracting are given of the chemical composition of both kinds of water. It is pointed out that the amount of chlorine present in the river-water is entirely dependent upon the volume of the river. In times of floods the quantity of chlorine may be reduced by one-half. The average composition of both kinds of water is shown in the following Table:—

Milligrams per Litre.	Spree Water.	Tegel Lake Water.
Residue	170–220	180–210
Lime	45–80	50–80
Chlorine	20–30	14–17
Permanganate of potash needed to oxydize	20–30	12–18
Ammonia	Trace to 0·4.	Trace.
Nitrites	..	..
Nitrates	0 to trace.	..
Micro-organisms per cubic centimetre	1,000 to over 100,000.	50–600

A similar comparison of the filtered water from both sources follows in a series of Tables.

The Spree water in the year 1886–7 contained from five to one hundred and thirty-eight germs; in the year 1887–8, fourteen to about two hundred and seventy-nine; and in the year 1888–9, from eight to one hundred and fifty-three germs per cubic centimetre. The figures for these years for the Lake Tegel water were, seven to one hundred and ninety-seven, four to ninety-eight, and eight to one hundred and thirty respectively. Careful inquiries showed that high numbers of bacteria were always due to disturb-

ances in the working of the filter-beds. The possibility of passing pathogenic germs through an ordinary sand-filter is discussed. Analyses of the filtered water from both sources are given in a tabulated form, as also the examination of the samples taken at different spots in the town.

G. R. R.

The Water-Supply of Pola. By FRANZ KRAUS.

(Wochenschrift des oesterreichischen Ingenieur- und Architekten-Vereines 1890, p. 272.)

The insanitary condition of the seaport of Pola has made the question of its water-supply of urgent importance. This question, it is stated, has been under the consideration of the authorities for years past, but nothing definite was accomplished until the appointment of the eminent geologist, Professor Stache, to investigate the matter, and the results of this investigation is the subject of this Paper. The chief characteristics of the Karst district (from which the water-supply will be drawn) are the numerous gorges and chasms intersecting the surface, and the large bowl or funnel-shaped cavities in the limestone rocks. The rapidity with which the rainfall is carried away in this area points to the connection of these cavities with underground channels, otherwise they would periodically fill and form lakes or expanses of water, and remain stagnant; the inference is that the fissures or channels have become blocked. On the position of such reservoirs or basins the volume and quality of the water would depend; the elevation of the catchment basin and its distance from the springs also influence the character of the water. The springs met with in the neighbourhood of Pola vary much in quality, and the best of them, the Caroline, is by no means excellent. Professor Stache proposes that the Caroline spring should be regarded as the chief source of supply, but recommends the tapping of other springs in order to meet any possible further demand for water. One of the first points to be accurately determined is the least annual rainfall area of catchment basin of the Caroline spring, as there are differences of opinion about it. Professor Stache himself assumes that it is identical with that of the Pisino, but it is held that the great distance (25 miles) between the two springs is opposed to such an assumption, as the difference of level or head is not sufficient to overcome the frictional resistance on such a long course. The next point would be to examine carefully the connection of the spring with the catchment-basin, and also with the harbour, and this latter connection should be stopped, in order to keep the spring free from sea-water. The Caroline spring has so many outlets that it is impossible to determine the exact amount of water conveyed by them, as some discharge directly into the harbour, even below sea-level; but what is required is the damming

up of the main gorge or channel in order to increase the head. This damming up, however, would only be admissible provided all the branch communications with the sea were hermetically closed. The water of the Caroline spring is wanting in freshness and sparkle, and this is the case with almost all the springs in the Karst area, unless the catchment basin is at a high level. In the limestones of the Karst district the rifts or fissures are generally at right-angles to the lie of the strata, and this is especially the case where there are faults, and these are frequently met with, and are due to earthquake shocks. In consequence of this physical feature of the Karst area, Professor Stache says it is impossible to obtain water by boring, and he is confirmed in his view by Dr. Tietze, and also by Professor Pilar, who, in his treatise "On the Water Conditions of the Croatian Karst," states that the Karlstadt-Firmana Railway Company undertook two borings at a cost of £2,500, in order to supply their stations with water, but none was reached. It is therefore evident that the Karst is an exceptional area, and that the usual geological conditions do not obtain. Professor Stache accordingly recommends an examination of the locality by a committee of experts, and he quotes the experience gained in carrying out successfully the drainage works in the Krain district, which are analogous to those for the water-supply of Pola.

W. H. E.

The Purification of the Seine. By R. Audra.

(Le Génie Civil, vol. xvii. 1890, p. 353.)

The works for purifying the Seine by diverting the sewage are progressing, and a short time ago, the contents of one of the large sewers, which used to open into the Seine in the heart of Paris, were carried into the large collecting main on the right bank and so taken out of the district. The island of St. Louis is transformed, and whereas nine main sewers used to open there all are now collected and pass under the bed of the river in a siphon, and open into the collecting main referred to above. The siphon consists of two tubes made of wrought-iron plates 0·394 inch thick riveted together, and each 15·75 inches diameter inside, fastened at a distance of 10·6 inches apart; they are placed in a bed of cement 5·9 feet wide, by 2·85 feet deep, at a height of 8 inches above the bottom of the trench. Its total length is 344 feet, and it is composed of straight pieces of pipe which lie in the actual bed of the river, and are connected to the curved pieces which rise up at each side. The junctions with the sewers consist of cast-iron pipes 15·75 inches diameter. The level of the collector on the island of St. Louis being 98·4 feet above datum, and that of the Quay of l'Hotel de Ville being 94·3 feet, the siphon has a final fall of 4·1 feet, and a dip of 21·7 feet where it crosses the Seine.

of this length has been of some difficulty. The eleven portions were put together on a sloping frame on the bank higher up stream, and the complete siphon was then slid down and fastened to two small pontoons. The whole mass weighed about 16 tons, and a load of 4 tons was added to increase the submersion. The whole was then allowed to slowly descend the stream, and passed between the piers of the bridges at an angle. The trench had, in the meantime, been prepared by laying a bed of concrete 8 inches thick at the bottom. The two tubes of the siphon were then lowered together into position, and four days after it had left the place where it was erected it was in its final position. The trench was then filled in, and the piles cut down level with the bed of the river by divers. The whole of the work is now completed, and a similar siphon is being constructed for the Isle de la Cité.

E. R. D.

River-Pollution in the United States.

By CHARLES C. BROWN, Member of the Engineers Club of St. Louis.

(Journal of the Association of Engineering Societies, Chicago, 1890, p. 475.)

The object of this Paper is to give as complete an idea as possible of the work that has been done in determining and showing to what pollution the streams of the United States are subject. It does not amount to much, and as the question is a very important one, the Author desires to draw attention to it, with special reference to those streams which are used as sources of water-supply for domestic purposes, and are at the same time used as drainage channels into which all sorts of filth are discharged. His own knowledge is confined to work done in the States of Maine, Massachusetts, Connecticut, New Jersey, Pennsylvania, New York and Illinois.

In the State of Maine the water-supplies are generally pure, nearly all being drawn from lakes with small watersheds, and little population to produce pollution, and the Reports of the State Board of Health are quoted, showing that the few river-supplies are also quite free from danger.

In the State of Massachusetts the work of investigation commenced as long ago as 1873, and has been more thorough than in any other part of the country, the Board of Health having examined the rivers Merrimack, Blackstone, Chicopee, Taunton, Charles, Sudbury and Concord, Neponset, and other sources of supply for the Boston Waterworks. The Merrimack is cited as an example of rivers used for sewerage and mill-drainage as well as for water-supply, and several Tables are given showing the amount of impurities in the water at different points above and below the

chief sources of the pollution. Chemical analysis shows that a large proportion of the polluting matter which enters the river is removed by deposition and by dilution. It was estimated by the Board of Health that it would be necessary to discharge 100 tons of dry soluble matter into the river per day to increase the amount of solid matter in solution by one grain per gallon, whereas the amount of chlorine discharged into the river was but little more than 1 ton per day. It was observed, however, that as the population and the number of mills on the banks increased there was an increase in the relative amount of pollution.

Thus the State Board's Report for 1887 gave the following comparative analysis of the water of the Merrimack above and below the two neighbouring cities of Lowell (pop. 65,000) and Lawrence (pop. 39,000), between which points there are some rapids which help to oxidize the impurities. The figures denote the number of parts per 100,000.

——	Date.	Ammonia.	Albuminoid Ammonia.	Chlorine.	Residue.			Hardness.
					Fixed.	Volatile.	Total.	
Above Lowell.	1886	0·0031	0·0155	0·3500	1·95	2·15	4·10	1·00
Below Lawrence	1886	0·0138	0·0244	0·4600	3·22	2·15	5·37	1·50

A comparison of these tests with others made in 1873 and 1879 shows a marked increase in that time in the chlorine and albuminoid ammonia, which shows that the pollution in populous and manufacturing districts is cumulative, and thus confirms the statements of the Rivers Pollution Commissioners of England. At the same time it is shown that between points on the river a few miles apart, where there has been no additional influx of pollution, the flow of the river has of itself tended to purification.

Similar tests are given of the water in the Blackstone river, which receives the sewage of the city of Worcester and the refuse liquors from wire works and other similar establishments.

Chemical and bacteriological examinations have also been made by the Boards of Health in the States of Connecticut, New Jersey, Pennsylvania, New York and Illinois, the results of which are given in this Paper. The tests made in Connecticut are too few in number to be of much use and they are not reproduced by the Author. In New Jersey the Passaic river has been long used for supplying water to Jersey City, to Newark and to some other cities and villages, and a suit is now pending for an injunction to prevent the discharge of sewage into the river from the new sewer system in the city of Passaic. In the State of Pennsylvania the work done has consisted principally in the investigation of the present and proposed water-supply for the city of Philadelphia, detailed inspections having been made of the water-sheds of the Schuylkill

and the Delaware rivers, of which the reports are to be found in the Reports of the Water Department of the city of Philadelphia. Some extracts therefrom are reproduced.

In the State of Illinois a very elaborate investigation of the Illinois river has been begun in connection with the proposed discharge of Chicago sewage with a diluting volume of lake water (from Lake Michigan) into the Illinois river through the Desplaines, and some of the results drawn from a preliminary report are given. They include a statement of the geological characteristics of the district, the population distribution, present and prospective; the extent of the basins tributary to the river, and detailed descriptions of the flow of water, levels and peculiarities of the Desplaines and Kankakee watersheds, which two streams unite to form the Illinois river. The results of this investigation are of the utmost importance, but embrace too large a field to be adequately reproduced in an abstract.

In the State of New York the original work has consisted principally in the investigation of the pollution of sources of potable water-supply for various towns and villages in the State. An inspection of Hudson river and its tributaries was begun last year. The conclusions to which the Author draws attention are to the effect that in the United States the work of investigation has been hitherto very insufficient, and that the more thorough that work has been, the more conclusively has it been shown that the continued use, even of the largest rivers, as both sewers and sources of water-supply cannot be permitted. The larger the river and the more favourable the conditions of purification, the longer can this double use be continued, but in the more thickly populated portions of the country the use of even the largest rivers is becoming questionable.

O. C. D. R.

Bacteriological Investigation of the Freiburg Water-Supply.

By Dr. Joseph Tils.

(Zeitschrift fuer Hygiene, vol. ix. part 2, p. 282.)

The impurities in service-water as determined by chemical analysis were rarely found to be present in sufficient quantities to constitute a pollution that could be regarded as toxic in amount even when such presumedly toxious ingredients were imbibed repeatedly in fractional doses. Until Koch explained his method of bacteriological research at the Berlin Cholera Conference of 1885, water was regarded as healthy or dangerous in accordance with its approach or otherwise to certain arbitrarily fixed standards, but since then, as it has become a recognized fact that all known infectious matters are of the nature of micro-organisms, the study of the germs present in potable waters has received great attention. The researches of previous investigators—Wolffhuegel, Bolton,

Bruenig, Maschek, Adametz and others are quoted, and the Author points out that, though the importance of minute bacteriological investigation is now universally admitted, there is a want of completeness in the work of many of these writers, inasmuch as they have failed to indicate the numbers of each different kind of germ present. It is important to ascertain the frequency of the appearances of such bacteria, because it may be assumed that the occurrence of these minute organisms follows the same general laws as those which affect the distribution of the higher forms of plant-life. From this aspect the study of the water-supply of Freiburg, one which adapts itself specially to this branch of the enquiry, has been undertaken by the Author. The threefold derivation of the water and the nature of the collecting grounds, and of the districts traversed are described. Samples of 100 cubic centimetres were collected for investigation in sterilized flasks, and within ten or fifteen minutes quantities of 1 cubic centimetre of the thoroughly well-shaken sample were introduced into nutritive gelatin, containing 10 per cent. of peptone, with all requisite precautions to ensure freedom from atmospheric impurities. Of each sample of water four plates were cast, and cultivated in a moist atmosphere at a temperature of from 18° to 20° Centigrade. After from three to six days the cultures were examined both qualitatively and quantitatively, and pure cultivations were carried out of the various colonies on gelatine, agar, potato, &c. Those colonies which induced liquefaction were absorbed by means of blotting paper, and destroyed by immersion in a solution of corrosive sublimate in glycerine. The plates were then examined at longer intervals to observe the non-liquefying organisms of slower growth. The Author, during the course of his experiments, succeeded in isolating fifty-nine different species, which he enumerates and classifies. Four bacilli, which are apparently undescribed, are dealt with at greater length, the bacillus tremelloïdes, *b.* cuticularis, *b.* filiformis, and a bacillus of the colour of flesh, all of them seemingly non-pathogenic.

In the Schlossberg water the average number of germs per cubic centimetre was twelve, in the Moesle water sixty, and in the Herdern water from ninety-four to two hundred; but the fluctuation found in each different kind of water at the various dates are shown graphically by means of a diagram. The Author sums up his observation in a series of conclusions, among which it is stated that the number of germs present in any water-supply varies in accordance with the extent to which that water is exposed to changes of temperature; that the different germs met with in potable waters have not yet been observed over sufficiently long periods to enable a systematic record to be prepared of their distribution; and that, in addition to the pathogenic germs known to occur in service water, there are others such as the Staphylococcus pyogenes aureus occasionally present. The results obtained are set forth in a tabulated form. G. R. R.

The Influence of the Sewage of Zurich upon the Number of Bacteria contained in the River Limmat.

By Carl Schlatter.

(Zeitschrift fuer Hygiene, vol. ix., 1890, p. 56.)

Attention is directed to the defects of the water-carriage system of sewage removal, and to the changes brought about in the methods of research by the application of bacteriological tests in addition to the chemical analyses formerly relied upon. The experiments of Dr. Frank upon the water of the Spree [1] are cited as an instance of the successful employment of these new tests. The Author states that his investigations have been undertaken to supplement the numerous chemical analyses of the water of the Limmat. As far back as June, 1881, it became necessary, in consequence of the complaints respecting the pollution caused by the sewage of Zurich, to prescribe standards of purity for all liquids discharged into the river. In March, 1881, the total flow of water in the Limmat was 125 cubic metres per second (27,512 gallons per second), and the estimated volume of sewage was 0·4 cubic metre per second (88 gallons per second). Samples of mixed sewage and river-water, taken at the prescribed distance of 50 metres below the outfall, were well within the stipulated degree of purity, as tested by permanganate of potash. Tables of gaugings of the volumes of sewage and river-water, taken at intervals of two hours on various dates, are given, showing considerable fluctuations in the proportion of sewage to river-water, varying from 1 to 101 in November to 1 to 161 in February.

The chemical tests carried out by Dr. Weber were, on the whole, so satisfactory, that, when the new sewerage works of Zurich were completed in 1883, the outfalls were carried into the mid-stream of the Limmat without further precautions. Many complaints, however, were subsequently made of the increased pollution, and Dr. Weber was instructed to carry out a fresh series of experiments, which took place from April 2, 1886, to March 12, 1887. The results obtained are set out in a tabulated form, which shows the parts by weight of permanganate of potash needed to reduce the dissolved and suspended organic impurities, the dry residue on evaporation, and the ash in each million parts of water. Only on one occasion was the amount of permanganate required in excess of the stipulated quantity (60 parts per million)—namely, on the evening of October 7, 1886, when 67·5 parts of permanganate of potash were needed. Dr. Weber's verdict, based on the standards originally laid down, was again favourable, but he expressed the opinion that other considerations should have weight. As the complaints still continued, Professor Wyss was

[1] Minutes of Proceedings Inst. C.E., vol. xcii. p. 473.

instructed to report on the subject and to pay special attention to bacteriological tests. These latter were entrusted to the Author, who prefaces his observation with an account of the influence of bacteria on the quality of drinking-water and the opinions of previous observers upon the subject.

The River Limmat, issuing from the lake, flows through Zurich in a straight course, with an average volume of 800,000 hectolitres [1] per diem, and then joins the Sihl, the volume of which is extremely variable, and which, at the time these investigations were in progress, was so inconsiderable as to permit of its being disregarded entirely in the calculations. This fact was advantageous inasmuch as a better estimate could be formed of the amount of the pollution actually due to the town sewage. After passing along a narrow channel, wherein, when the water is low, almost the whole volume is utilized for the motive power of the pumping-station, the river regains its original width and velocity at Wipkingen. Here the three main outfalls discharge the sewage and give rise to three great black currents of fouled water, which may be traced for a considerable distance along the stream. Lower down, several smaller sewers, enumerated by the Author, add their quota of sewage, so that, altogether, the water fouled by a population of 67,000 persons passes into the Limmat. A calculation is given to show that the dry-weather flow of the sewers may amount to from 17,000 to 20,000 cubic metres per diem, the average volume of the Limmat being 8,000,000 cubic metres per day, and that of the Sihl 1,000,000 cubic metres daily. Below Wipkingen the volume and velocity of the stream, except as far as they may be affected by the various weirs, remain unchanged, there being no considerable affluents and no factories or villages of importance. The points from which the tests were to be taken were practically settled by the nature of the inquiry, and are explained by reference to a plan; they were ten in number, and embraced a range of about 14 kilometres (8·7 miles) of the stream, beginning below the town, where the water was still unmixed with sewage, then at various points immediately below the outfalls, and at others at considerable distances onwards as far as Dietikon. All samples were taken at mid-stream. The tests were taken at fortnightly intervals, extending from the beginning of January to the end of April, 1889. The specimens were dealt with immediately after they were obtained, the time elapsing never being greater than one and half hour. The precautions taken to fill the Erlenmeyer flasks and to obtain cultures absolutely free from foreign germs are described. Owing to the number of the colonies, the tests were diluted to the hundredth of a cubic centimetre, three casts of each being taken; but comparative plates, diluted to $\frac{1}{50}$ only, were in each case obtained as a check upon the results. Tables are given of the eighteen sets of experiments, each set embodying the results of forty tests. Temperature,

[1] *Sic* Myrialitres.

water-levels at various points, and rapidity of current were also noted. A comparison of the Tables shows that the number of germs in the water of the Lake of Zurich fluctuates but little, and varies from one hundred to two hundred per cubic centimetre. Even in its passage through the town the water of the Limmat becomes much polluted; but the admixture with the sewage-water causes an astonishing rise in the number of germs, and the river-water, which had previously contained from one thousand to two thousand germs per cubic centimetre, is at once found to contain up to half a million germs in a like volume. The further away from the outfalls that the samples were taken, the smaller became the number of germs. At Dietikon, 10 kilometres (6·21 miles) below the point of admixture with the sewage, the river-water was frequently quite as pure as it was above the town, and in some cases even better results, due to the very marked self-purifying powers of the river, were obtained at Dietikon. The more rapid was the current, the smaller was the relative improvement, from which the Author surmises that the purifying action is rather one of deposition than of the chemical influence of oxygen, &c., as has been sometimes supposed.

G. R. R.

Disinfecting-Apparatus for Clothing, Bedding, etc.

(Annalen fuer Gewerbe und Bauwesen, October, 1890, p. 145.)

By reference to diagrams a description is given of two varieties of the apparatus, the one having a rectangular chamber, the other being cylindrical in form. The frame to receive the objects to be disinfected is arranged to run in and out on rails. There is a hinged opening in front, the other end being closed, but provision is made so that in cases where the apparatus is to be built into a wall, and all communication between infected objects and the persons in charge of the operations has to be cut off, the frame can be run in at one side and out at the other when the treatment is over. The heating is effected by means of two coils of copper steam-pipes above and below. The inlet for the supply of dry steam, which must, according to the regulations of the Berlin State Sanitary Department, be in the form of a jet, is so contrived that all condensed water is removed before the steam is admitted, and the chamber and its contents are heated to 70° Centigrade before free steam is blown in. By means of throttle-valves the air forced out of the disinfecting chamber into the chimney, and the admission of air into the chamber, can be regulated. The entire process of disinfection, during which a temperature of 105° Centigrade is reached, even in the middle of large bundles of clothing, lasts about half an hour. The apparatus is manufactured by the firm of Oscar Schimmel & Co., of Chemnitz.

G. R. R.

Works for the Automatic Supply of Brine at Syracuse, U.S.

By C. B. Brush, M. Am. Soc. C.E.

(Transactions of the American Society of Civil Engineers, vol. xxiii., 1890, p. 95.)

The old salt works at Syracuse, which at one time were the largest in the country, had experienced a great falling off in their production, owing partly to the exhaustion of their natural supply; and to resuscitate the industry, the Tully Pipe-line Company have established works for the constant supply of water saturated with salt.

The brine is delivered at Syracuse into an open reservoir of 5 million gallons, the fresh water being obtained by a gravitation supply from the Tully Lakes, at a distance of 23 miles from the city, and converted into brine during its passage to Syracuse by passing it through wells sunk into the beds of rock-salt.

From the source of supply, which is about 800 feet above the level of the reservoir, the fresh water is conveyed in a 12-inch main; and the wells are located on its course, at a distance of 3 miles from the source, where the ground is about 400 feet lower. At this point twelve wells have been sunk into the beds of rock-salt, which are found at a depth of 1,200 feet below the surface. The first bed has a thickness of 43 feet, and the second of 54 feet, the two beds being separated by a layer of slate rock, 25 feet thick.

The wells are arranged in three groups, about 1,000 feet apart, each group containing four wells placed at the corners of a rectangle 400 feet by 150 feet. Each well consists of a 6-inch bore-pipe, with an interior pipe 3 inches in diameter. The fresh water is led down to the rock-salt through the annular space, and returns through the central pipe as saturated brine. As the salt is dissolved, the cavity at the base of each well is enlarged, and the saturation becomes more rapid.

The brine rising from each well is stored in a regulating tank, having a capacity of 1 million gallons, and provided with a self-acting valve on the principle of an ordinary ball-cock, by which the admission of water from the main is controlled by the level of the brine. From these tanks the brine is conveyed by the 12-inch main to the Syracuse reservoir, which is also commanded by a self-acting valve of the same kind.

At every point the flow is automatically controlled, and is limited by the draw-off at the Syracuse reservoir. At the present time the supply is about 300,000 gallons per day, with a saturation of 90 per cent., and it is expected that 95 per cent. of saturation will eventually be obtained.

In the execution of the work, several gangs of the Onondaga Indians were employed; and when treated with a proper dignity they proved to be the best and most reliable of workmen.

T. C. F.

Experimental Determination of Moments of Inertia.

By Prof. M. Kohn.

(Der Civilingenieur, 1890, p. 7.)

The methods given in mechanical text-books for the experimental determinations of the moment of inertia of a solid body consists in suspending the body on an axis parallel with and a known distance r from the axis passing through the centre of gravity and observing the periodic time t of oscillation. If G is the weight of the body the moment of inertia is given by—

$$T = \frac{G\,t^2}{\pi^2}\,r.$$

Simple as this method appears on paper, the Author points out that its practical application is very difficult, principally on account of the apparatus required to suspend heavy bodies in the manner indicated, and the error introduced by friction in the suspending bearings. To obviate these difficulties he has devised another method, which does not require special apparatus for suspending the body, which may be tested in its own bearings. The error due to journal friction is also eliminated. The method is particularly adapted to measure the moment of inertia of cylindrical bodies such as a fly-wheel or a pulley. A flexible band is laid round the pulley and weighted at its ends with known weights, G_1 and G_2. Let R represent the journal friction reduced to the circumference, and M the mass of the body also reduced to the circumference, then the acceleration produced by the application of the weights is,

$$p = \frac{G_1 - G_2 - R}{\frac{G_1 + G_2}{g} + M}.$$

The difference $G_1 - G_2$ between the weights, must of course, exceed the frictional resistance R. The movement being one of uniform acceleration it follows that the distance s, through which the heavier weight falls in t seconds is, $s = \frac{p\,t^2}{2}$, and combining this with the above equation we obtain,

$$2\,s = t^2 \frac{G_1 - G_2 - R}{\frac{G_1 + G_2}{g} + M}.$$

This formula could be used to determine M, and therefore the moment of inertia, if the value of R were accurately known. This is, however, not the case, the friction being an uncertain factor;

and to eliminate the error which might be introduced by an erroneous estimate of journal friction, the Author makes a second experiment, taking from G_2 a certain weight a and adding it to G_1. This will increase the acceleration without altering the frictional resistance, and a distance s_1 larger than s will now be traversed in the same time t. The above formula becomes,

$$s_1 = t^2 \frac{G_1 - G_2 + 2a - R}{\frac{G_1 + G_2}{g} + M},$$

and by combining the two formulas he finds the moment of inertia (r being the radius of the pulley)—

$$T = M r^2 = \left(\frac{t^2 a}{s_1 - s} - \frac{G_1 + G_2}{g}\right) r^2.$$

An example is given of the determination of the moment of inertia of a line of shafting with pulleys, the time of observation being two seconds, and the distances traversed by the weights 1·5 and 2·7 feet respectively.

G. K.

Testing-Laboratory for Agricultural Machines.
By G. Mareschal.

(Le Génie Civil, vol. xviii., 1890, p. 33. 3 Figs.)

The French Minister of Agriculture has founded a new laboratory for the special purpose of testing agricultural machinery, and the Paris Municipal Council granted a site in the Rue Jenner of some 3,950 square yards in extent for a period of fifteen years. The test-room is reached by a paved incline, and the most frequent tests are made upon (1) rotary apparatus, such as mills, beaters, &c.; (2) apparatus worked by traction such as carts, ploughs, &c.; (3) apparatus worked by lever or crank-handle, such as presses, pumps, &c. The test-room contains a gas-engine of 7 HP., dynamometers with automatic recording gear; counters, balances, &c., and a small mechanics' shop is provided. The main shaft is 39 feet long and $2\frac{3}{4}$ inches diameter, and is carried at a height of 3 feet 3 inches above the ground by four plummer-blocks; it is made in three pieces coupled together. Part of the shaft is outside the building, opposite a shed where tests are made of those machines which when working cause dust.

When more than 7 HP. is required a portable engine is used. A circular path for the test of machinery worked by animal power is provided, and shortly a column 60 feet high for pump tests will be erected; floors will be placed at 16 feet apart and a crane fixed at the top, and gauges provided.

The driving pulleys in the test-shop are of a special design. It is necessary to have them adjustable for different diameters, and instead of using the ordinary method of segments, which can be moved out or in by special apparatus, but which have the disadvantage that the periphery is only circular for one size and is always discontinuous, the following plan is adopted. Two disks of the same diameter are provided, one of which has a boss, solid, with it, and is keyed to the shaft; the other is a simple disk which can be bolted on to the end of the above-mentioned boss, and when in position the two disks are parallel and separated by the length of the boss. The faces of the two disks which are opposite to each other have a series of concentric grooves of different diameters cut in them, and for each groove a thin flexible steel plate is provided of the exact length to form the pulley rim.

Two of these pulleys allow of changing the belt-speed from 160 to 1,900 feet per minute, and with a third a variation from 50 to 5,800 feet per minute will be possible, while the engine runs at 165 revolutions constantly. Tests on rotary machines are made with a dynamometer consisting of two pulleys, one driven from the main shaft and the other driving the machine, the power being transmitted from one pulley to the other by calibrated springs, which cause a pencil to draw a diagram on a rotating cylinder covered with paper; a totaliser gives the HP. transmitted and a counter is attached. All the instruments are connected electrically so that they can be started and stopped at the same instant. A special traction dynamometer has been made by Mr. Ringelmann, the director.

A charge is made for each test and a certificate supplied. The laboratory was opened in January, 1890, and twenty-eight machines have already been tested.

E. R. D.

Universal Dynamometer-Brake. By C. Jimels.

(Le Génie Civil, vol. xvii., 1890, p. 375. 3 Figs.)

The measurement of constant forces, unless very great, is a simple matter, but when they vary rapidly it is not easy. The Author considers that a good transmission-dynamometer is still wanting. Mr. G. Trouvé has constructed an apparatus which will act as an absorption- or transmission-dynamometer. After describing what is required in a dynamometer, the Author remarks that an indicator diagram gives merely the power produced in the cylinder, and not that transmitted to the machine worked. He refers to the ordinary Prony brake and states that up till the present time other dynamometers have been mostly laboratory instruments. Trouvé's apparatus consists of two separate parts, one intended to measure the force acting, and the other the distance passed through.

For the measurement of the forces he employs a rotary spring dynamometer, and uses a flat spring placed in the axis of the dynamometer in order to be free of the centrifugal action, while at the same time it is protected from blows. The spring is under simple torsion without friction and well within its elastic limit, so as to ensure constancy. The spindle is hollow and made up of two concentric tubes, to which are fixed the ends of the spring, and which can follow its torsional movement. To the end of one tube is fixed a sleeve cut away in an inclined plane; another similar sleeve, free on the second tube, is brought to a position of rest against the first by a light spiral spring.

At first a screw-thread was used, but with that the dynamometer could only be used in one direction of rotation, but with tempered steel inclined planes more exact results are obtained, and they are independent of the direction of rotation; the second sleeve can only move in a longitudinal direction, and moves the pointer over the scale.

The graduation is effected as follows. After having fixed the axis of the dynamometer spring at one end to the motor shaft, a double balanced lever is fixed to the other end, the arm of the lever being chosen of such a length that 1 lb. hung on the extremity would represent a foot-pound of work. One end of the lever is then loaded so as to represent the maximum torsion of the spring. The motor is then turned slowly by hand until the loaded lever occupies a horizontal position, and the position of the needle is marked on the dial. The graduation proceeds from maximum to minimum. The measurement of angular velocity is required for the second factor, and there are already a large number of speed counters which effect such a purpose, but Mr. Trouvé uses a tube bent into the form of an S, and fixed in the middle to a hollow spindle which communicates with a U-shaped gauge. The tube revolves with the motor under test, and its rotation causes a depression more or less rapid in the height of the fluid in the U-tube. In cases where the speed is too slow one of the ordinary methods is used. The U-tube is graduated by experiment. The variation in the column reaches in some cases several yards in height, so that intermediate speeds can be easily read off. A view is shown of an absorption dynamometer used for the tests of a motor giving out from 220–290 foot-lbs. of work per second, and making 2,400 revolutions per minute. In order to absorb the power thin plates are placed on the axis which act as fans; three or four sizes can be used, and from the results obtained curves can be drawn from which readings can be deducted for other speeds. For greater loads and lower speeds the plates may revolve in water or mercury.

For motors of large power, of high or low speed, the absorption is obtained by a dynamo into the outside circuit of which are interposed variable resistances suitable to the special test conditions. In this case the S-shaped tube is replaced by an instrument similar to that used for the measurement of the forces, but of smaller dimensions and only used as a speed indicator. The transmission

dynamometer is made in a similar manner, and is provided with a pulley at each end, one driven by the motor, the other driving the machines. E. R. D.

On the Thermal Action of Steam-engine Cylinder-walls, as shown by the Experiments of Mr. Bryan Donkin, Jun.

By Professor DWELSHAUVERS DERY.

(Bulletin de la Société Industrielle de Mulhouse, August-Sept. 1890, p. 289.)

Fifteen years ago the thermal action of the walls of a cylinder first began to occupy attention. Many experiments to determine their influence were made by Hirn, Hallauer, and others of the Alsatian school, by Schmidt, of Prague, and Professor Zeuner. The discussions which ensued were almost wholly based on theory, for no practical knowledge of the actual phenomena taking place inside the cylinder existed at that time. Only by the analytical method, and by a free use of formulas, was any attempt made to trace the exchange of heat between the walls and the steam. Direct experiment and actual facts were needed, instead of formulas and coefficients based upon conditions often totally different from those obtained in practice.

In 1868, Mr. Bryan Donkin constructed a small apparatus to show the effects of heat passing between the walls and the steam, as the indicator shows the pressure of the steam. It consisted of an ordinary boiler glass gauge, closed at one end, and fixed at the other side into a tube screwed on to the indicator-cock, thus forming a transparent prolongation of the cylinder-wall in contact with the steam. This tube exhibited the phenomena of condensation and re-evaporation at every stroke of an engine.

But a single glass tube could not protect the steam from the cooling effects of radiation. The diameter of the glass was therefore increased, and its length diminished; it was surrounded with a second tube, and thus a jacket of air was interposed between the two, as shown by a drawing in the original Paper. At speeds varying from 30 to 150 revolutions per minute, the effects of condensation and re-evaporation were still more clearly visible.

Another modification was then introduced into the instrument. As before, the inner and outer vertical glass cylinders were fixed between two metal plates, and air was introduced into the intervening space. But the pipe connecting the inner cylinder with the engine cylinder was prolonged to a certain height above the bottom of the apparatus, so that a small quantity of water could be placed below it. In 1888 this apparatus was fixed on the low-pressure cylinder of a Woolf engine at Bermondsey. The space within the inner cylinder was filled with cold water to a depth of about $\frac{3}{4}$ inch; this water disappeared in three or four minutes. During the exhaust stroke it boiled furiously. When, however, the instrument was screwed on to the condenser, where the temperature was much lower, $\frac{1}{8}$-inch of water was

not evaporated in several hours; and when fixed on the low-pressure cylinder, it was observed that the bottom of the inner cylinder of the apparatus never seemed to be absolutely dry. When on the small cylinder of this engine, and with a boiler-pressure of five atmospheres, the steam was seen to form and pass into the apparatus in the form of a cloud; in two minutes about five-sixths of the water was evaporated, but the remaining sixth had not wholly disappeared in twenty-three minutes. These experiments show that when the instrument is fixed on the large cylinder of the engine a certain quantity of water remains at the bottom. If more be added, it evaporates, or if it passes off, it forms again. The quantity seems to be unalterable. It probably depends on the temperature of the apparatus; the higher the latter, the quicker the evaporation of the water.

In 1889 the instrument was remodelled. The two concentric tubes or cylinders between metal plates were retained, but the outer one alone was now of glass. The inner was of metal, open at the top, and closed by a discharge-pipe at the bottom. From a reservoir above, a stream of water of known temperature was turned through the inner cylinder. Notwithstanding the heat communicated to the walls, this water could be kept at any temperature by manipulating the cocks. The annular space between the glass and metal cylinders was filled with steam from the engine cylinder. The temperature of the water was taken on entering and on leaving the inner cylinder, and a thermometer, to give the temperature of the metal, was placed in a small hole in the metal wall, filled with mercury. The interior of the instrument was lighted up by a gas-jet on the outside, the heat of which prevented the formation of dew upon the glass cylinder, and kept it clear.

The following are the results of two experiments made upon the larger cylinder of a Woolf engine with this apparatus. The inner cylinder of the instrument was of thin copper. The initial pressure in the engine cylinder was 7 lbs. absolute per square inch, with 2 lbs. absolute vacuum; the corresponding temperatures would be 177° Fahrenheit and 126° Fahrenheit. In the first experiment, the temperature of the walls of the inner cylinder was maintained at 103° Fahrenheit by a current of cold water. This was much below the initial and final temperatures. Upon both the glass and the metal large drops of water from $\frac{3}{16}$ to $\frac{1}{8}$ inch in diameter were visible, running down the glass, and there was a permanent deposit of water, boiling periodically, at the bottom of the apparatus. The quantity of water passing through the cylinder was taken, as also the temperature in and out, and the quantity of heat given up by the condensed vapour deducted from it.

During a second experiment with the same initial temperature of the steam, viz., 177° Fahrenheit, the walls of the inner tube were kept at 127° Fahrenheit, or the same temperature as the exhaust steam. This time dew was formed on the metal, but

not on the glass walls. The drops were only about $\frac{1}{16}$ inch in diameter, and no longer ran down the walls, nor was any water deposited at the bottom. The quantity of heat given up by the steam to the water was three times less than before. This marked difference is solely due to a variation of temperature of only 24° Fahrenheit in the walls of the instrument. A third experiment was made with water in the inner cylinder at 180° Fahrenheit, that is, equal to the highest temperature of the steam in the engine cylinder. No dew whatever appeared on the metal walls, and the steam remained clear and free from mist.

In 1889 the instrument was applied to a new purpose, and an endeavour made to discover the principles on which heat is propagated through the metal. The walls of the instrument were made of cast-iron, and thermometers placed at different depths in the thickness of the metal. Small holes were drilled, about $\frac{1}{8}$ inch in diameter, and $2\frac{1}{2}$ inches deep, and spaced out spirally about 1 inch apart. These holes being filled with mercury, a small thermometer was plunged successively into each. The results obtained are given in diagrams representing the thermal gradients, the ordinates of which are the temperatures observed, and the abscissæ the distances of the different holes from the surface of the cylinder. The external temperature of the metal was taken in a similar way.

Thus the "Revealer," in its various forms, may be used to study the heat effects of a steam-engine, of the steam-jacket, of superheated steam, of different speeds, and to indicate the exchanges of heat between the metal and the steam, as also the propagation of heat through the walls.

Mr. Bryan Donkin has been able to verify what Professor Kirsch supposed, that the mean temperature of the walls is higher at the extreme ends of a cylinder than in the middle. He divides the thickness of the wall into two distinct portions, each acting independently of the other, the smaller being on the inner side, and the other and far larger part on the outer side of the cylinder (non-jacketed). The first part may be called the intermittent or periodic thickness, because the thermometer nearest the piston shows that its temperature rises and falls slightly with each revolution of the engine, when running slowly. Probably the internal surface of the wall in direct contact with the steam is affected by all its changes of temperature; but the further the heat penetrates in the thickness of the metal, the less the temperature varies, till a certain limit in the wall is reached, where the fluctuations at each stroke cease. In the smaller intermittent part, the heat passes from the steam to the metal and *vice versâ*. In the larger or constant region, the flow of heat is always in the same direction, from the interior to the exterior of the cylinder. At the division already mentioned, a reservoir of heat is formed, which is sometimes reinforced from the interior of the cylinder, and sometimes restores what it has received; but which is also continually sending on heat by radiation towards the

exterior surface. The outward radiation of heat, therefore, takes place only in the larger or constant thickness, the temperature of which is neither the varying temperature of the internal wall, nor that of the external air or felt covering. These important and characteristic facts neutralize all attempts to apply empirical formulas to these phenomena.

It is difficult at present to sum up the results of the experiments, but the following points may be noted. The thickness of the intermittent part of the wall is very small in comparison with the other part, being in about the proportion of $\frac{1}{10}$ to $\frac{9}{10}$ inch. Its actual depth varies with the working conditions of the engine, and especially with the speed; it depends partly upon the metal used, which, as in this case, is usually cast-iron. In the cylinder-wall of a vertical steam-engine non-jacketed, if well covered, the thermal gradient in the constant part deviates slightly from the horizontal. The mean temperature of the wall is generally higher than the mean temperature of the steam in the cylinder taken from the diagrams.

Experiments have also been made with a "double" apparatus. The thickness of the walls of one cylinder was 1 inch, and of the other $\frac{3}{8}$ inch. They were placed successively on the two cylinders of a compound steam-engine, and temperature holes made in them. The results obtained are much the same as those with a single instrument.

A small instrument has also been designed to analyze the action of the steam-jacket. The inner of the two concentric cast-iron vertical cylinders was made 1 inch, and the outer $\frac{5}{8}$ inch thick. Steam from the boiler was introduced into the annular space between them, and the inner cylinder placed in communication with the cylinder of an engine. To keep the internal surface of this cylinder clean and polished, in imitation of the engine cylinder, it was fitted with a piston worked by hand. The steam-jacket was provided with two pipes, and the water condensed in the jacket divided by a particular arrangement into two distinct portions, that from the surface of the inner, and that from the surface of the outer vertical cylinder. These quantities were separately weighed, to determine the amount of heat passing through each wall. The instrument was well covered, and small holes were filled with mercury, to take the temperature of the metal at different depths as before. It was placed on the large cylinder of the engine at Bermondsey. The various thermal gradients taken with different pressures of steam in the jacket are given in the original Paper, which is also illustrated by drawings of the original instrument and its modifications.[1]

A drawing is given there also, showing the exact appearance of the wet surface of the steam-jacket. This surface is covered with dew, and $\frac{1}{8}$ inch diameter drops are formed which run down the two vertical sides of the jacket. B. D.

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[1] Some of the illustrations may be seen in Min. Proc. Inst. C.E., vol. c. p. 347.

Apparatus for the Purification of Feed-Water for Boilers.

(Annalen fuer Gewerbe und Bauwesen, vol. xxvii., 1890, p. 218.)

By reference to illustrations, a method of freeing hard water from the dissolved impurities tending to the formation of boiler-scale is described, the invention of Mr. C. Kleyer, of Carlsruhe. In its essential features it consists of an upper and lower reservoir, being tanks placed one over the other, the upper one at least being steam-jacketed. The waste steam is admitted into the outer lining to warm a measured volume of water in the upper tank, equivalent to one filling of the boiler. As soon as this water has been raised to a temperature of 60° Centigrade (140° Fahrenheit) it is treated with a chemical mixture, adjusted so as to lead to the precipitation of all the more insoluble scale-forming compounds, and the contents are stirred by blowing in steam. After twenty minutes' stirring the temperature will have risen to from 70° to 75° Centigrade (158° to 167° Fahrenheit), and complete decomposition will have been effected. The steam is then turned off, and the precipitate is allowed to settle. The water is drawn off by a special standing waste-pipe, with slits reaching down to within a couple of inches of the bottom of the tank, by which means the sludge is retained, and only the clear water descends through a filter into the lower tank. The mud or sludge can then be forced out of the bottom of the tank and a fresh supply of water is pumped in for treatment. The entire operation lasts two hours and a half. G. R. R.

Triple-Expansion Engines. By H. Lorenz.

(Der Civilingenieur, 1890, p. 331.)

After some introductory remarks concerning the history of triple-expansion engines and a general description of various types, the author points out that, judging from the diagrams only, it might appear as if a triple engine were less economical than a single engine, on account of the gaps between the diagrams of the three cylinders. These losses are, however, more than compensated by the fact that a very large proportion of the steam introduced into the HP. cylinder remains active as steam right through the cycle, the condensation being in a good triple engine only 11 per cent. or even less, whereas in a single engine it may amount to 50 per cent. Thus the efficiency of a triple engine, notwithstanding the gaps in its diagram, is high, amounting, with steam containing 3 per cent. of water, to about 78 per cent. of the total power which could be obtained if the Carnot cycle were carried out perfectly, whilst a compound engine shows only about 60 per cent. efficiency. It is, however, essential to have as near as possible equal temperature drop in the three cylinders. If, with an engine working with 150 lbs. steam, it be required to have, say, 38° Centigrade (68°·40 Fahrenheit) drop in each cylinder, the ratio

of their volumes must be as 1 : 2·5 : 7·5, which agrees fairly well with general practice and with Mudd's rule, according to which the diameters of the three cylinders should be as 3 : 5 : 8. Adopting these proportions it will be found that the power is also fairly divided between the three cylinders. The author next discusses the problem of converting a compound into a triple expansion engine, the influence of clearance, the question of steam-jacketing, and the sequence of cylinders. The influence of the inertia of moving parts is also fully investigated.

G. K.

The Baldwin Four-Cylinder Compound Locomotive.

(Engineering News, New York, September 6, 1890, pp. 216, 224.)

This locomotive, which has already been described,[1] has been tested for economy by comparative trials with one of the standard locomotives on the Baltimore and Ohio Railroad, U.S.A. The two engines are alike in all respects, excepting that the compound has four cylinders and the standard has two only.

Total weight in working order	105,460 lbs.
Driving weight	72,000 „
Weight of tender, empty	29,500 „
Area of fire-grate	25½ sq. ft.
„ heating-surface	1,504 „

The first cylinders of the compound engine are 12 inches and $12\frac{3}{16}$ inches in diameter; the second cylinders are 20 inches. The cylinders of the standard engine are 19 inches in diameter. The stroke for both engines is 24 inches.

The engines were each tried on a "limited express" train, between Philadelphia and Washington, 133 miles, or 266 miles with return trip; timed to make the run at the rate of 48 miles per hour, including four stops. There are numerous inclines of 42 feet per mile on the Philadelphia division; with one of 76 feet, and another of 55 feet per mile. The Washington division is fairly level. The train was composed of four cars between Philadelphia and Canton, and three between Canton and Washington. The weight of the train of four cars, with engine and tender, was approximately 210½ (American) tons; and that of the three-car train, 186½ tons. Car-miles travelled, 979 miles.

	Compound.	Standard.
Coal consumed (including getting up steam and banking fires)	13,942 lbs.	16,389 lbs.
Coal consumed, per mile run	52·40 „	61·61 „
Water evaporated, supplied at 60° Fahrenheit	84,506 „	88,040 „
Water evaporated, per lb. of coal	6·06 „	5·37 „
Average pressure in the boiler	148·2 „	129·6 „
Indicator HP., average	638·5	655·5

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[1] Minutes of Proceedings Inst. C.E., vol. cii. p. 384.

It thus appears that the compound engine consumed 14 per cent. less coal, and 3·2 per cent. less water, than the standard engine. From the results of selected diagrams, it appears that steam was cut off at 55 per cent. in the first cylinder of the compound engine, and at 39 per cent. in the standard engine. The compound engine steamed much more freely than the standard engine; whilst the compound exhaust disturbed the fire much less than the exhaust from the standard engine. It may be added that, with 3½-inch exhaust-nozzles in both engines, the compound engine made steam more rapidly than it was used; whilst in the standard engine the blast was not sharp enough to keep up the steam-pressure.

D. K. C.

An Electric Head-light for Locomotives.

(Electrical World, New York, vol. xvi., 1890, p. 220. 2 Figs.)

As train-speeds increase, the headlights must be more and more powerful in order to produce any useful effect, and the oil lamp has been found in the United States incapable in any practical form of giving a sufficiently penetrating beam. The electric apparatus described in the article has been put into practical use on several roads, and it is stated that the results have been satisfactory. It is the invention of Mr. G. C. Pyle, of Indianapolis. The difficulties to be overcome in designing such an apparatus are numerous. It is necessary to have an electric light plant small enough to be readily placed somewhere on or about the locomotive, and of simple construction, so as to add little to the engine-driver's duties. The greatest difficulty, however, is caused by the vibration on a rough track. The plant consists of a small engine and dynamo coupled together, and placed on top of the boiler between the chimney and the head-light.

The engine is one of the multiple-cylinder class, with four cylinders placed symmetrically round a common shaft.

Its full output is 3 HP., and a pipe ¾-inch diameter supplies it with steam from the fire-box end of the boiler, so that the regulation is controlled by the driver. The dynamo is extremely compact and simple, and as it is only designed to supply one arc lamp no special regulation is necessary, nor do the brushes require moving. The engine and dynamo are encased so that flying cinders and dirt are excluded, and the total weight of the combination is only 650 lbs., and occupies a space 28 inches long, 15 inches wide, and 17 inches high. The normal speed is 425 turns per minute. In fitting the apparatus to a locomotive the head-light is usually moved forward a little to secure the necessary space. The lamp used has a rack feed, and is operated in a very simple manner; the carbons run in guides which steady them at points quite close to the arc, so that any vibration of the engine will not jar them

sufficiently either to cause fracture or to interrupt the arc. The new carbons are readily put in by lifting the rod and carbon holder catching the pawl upon the ratchet-wheel and entering the carbons through the guides into the holders; by unloosing the pawl until the carbons meet, the lamp is prepared for lighting. Hand-nuts are provided at the base to allow it to be focussed properly. A set screw and lifting screw also at the base serve to raise the apparatus into its proper focus in a vertical plane, and the entire lamp can be removed from the case if it is necessary to make repairs or to clean it more carefully than can be done readily in the case. The lower electrode is of copper so as to avoid the necessity of having a focussing lamp, as that form is usually complicated and liable to get out of order. The wasting of the copper is said to be very gradual, and when it becomes blunt, it can be taken out, filed down, and put back in nearly the same place as before. The light is nominally 2000 candle-power, which appears sufficient for ordinary use. Experiments have been going on for several years, and now the light has come into regular use on a considerable number of railways of which a list is given. On some a large number are said to be used.

A dozen or fifteen telegraph poles can be seen in front of the engine regularly, even when the weather is not altogether good; and on an exceptionally clear night as many as thirty-three poles have been seen. The poles run about thirty to the mile; even in bad weather the view for 1,000 or 1,200 feet ahead is stated to be as good as in daylight. The only objection appears to be that when running towards a powerful light of this kind on a double line of rails it might be a little difficult to distinguish landmarks by reason of the glare: but from experiments made on the Cincinnati, Hamilton and Dayton line, there seems to be little practical difficulty.

E. R. D.

An Account of Experiments on the Double-Screw Ferry-boat "Bergen." By B. F. Isherwood.

(Journal of the American Society of Civil Engineers, August 1890, p. 251.)

The "Bergen" is a double-ended ferry-boat propelled by two screws, one of which is at the bow, and the other at the stern.

The following are the principal dimensions:—

Length, extreme	200 feet
„ on waterline	198 „
Breadth, extreme	62 „
„ on waterline	32 feet 5 inches
Depth	18 feet
Draught	10 „
Displacement	560 tons
Weight of steel in hull	320 tons
„ of machinery and water in boiler	180 tons

There are two boilers, of the cylindrical locomotive type, having a combined heating-surface of 3,230 square feet, and a grate-surface of 84 square feet.

When the vessel was propelled by the after-screw alone, the forward one being removed, the speed obtained was 10·49 knots. The I.HP. was 440, the revolutions 142 per minute, and the slip 16 per cent.

When the forward-screw was tried alone, the after-one being removed, the speed was 9·6 knots. The I.HP. was 465, the revolutions 145, and the slip 24·5 per cent. On a third trial, with both screws working together, the conditions were not the same as on the other two, the bottom of the vessel being foul.

The speed with both screws was 10·88 knots, the engines developing 666 HP., with 142 revolutions. The slip was 12·9 per cent.

In the HP. given above the power developed by the propelling-engines alone is included, an additional 53 HP. being developed by the auxiliary engines for pumps, &c.

It was estimated that the forward-screw increased the resistance of the vessel by 23·5 per cent., and that its propelling efficiency was only 43 per cent. of that of the after-screw.

S. W. B.

On Machine Ventilation in Driving Levels at Dudweiler.

By G. Engeleke.

(Zeitschrift fuer das Berg-, Huetten- und Salinen-Wesen, 1890, p. 286.)

At the Dudweiler mine at Saarbrücken, the method of ventilating narrow workings by means of small fans, driven by compressed air placed in the main intake air-current, and blowing the air forward, has been adopted on a considerable scale. Two classes of fans with engines attached and driven by compressed air are in use. The earlier form made by Pinette and Company, of Chalons sur Saône, is a centrifugal fan, 500 millimetres in diameter, of Sers pattern, having twenty-eight radial blades slightly curved and axial suction passages on both sides. The blades are mounted on a disk with a cone fronting the admission passage on either side. The fan is driven by a strap from the shaft of the engine, the exhaust from which passes into the blowing main and so assists in the ventilation. As the length of stroke is very small, only 100 millimetres (4 inches) the fan can be driven very rapidly from 450 to 950 revolutions per minute, the pressure varying from 10 to 58 millimetres of water, the velocity from 12·3 to 295 metres per second, and the discharge from 0·745 to 2·080 cubic metres per second at these speeds. The cost of these fans is about £56 each.

Another and more extensively used method of ventilation is that

of Dingler, who uses a later modification of Sers fan. This is a fan with eight trapeziform blades 140 millimetres broad, set a little out of a radial direction on a disk 695 millimetres in diameter. The disk is slightly dished and has a central cone facing the air inlet. The axis of the fan carries the crank of the driving engine, so that no intermediate gearing is used. The length of stroke is only 50 millimetres (2 inches). The cost of these fans, of which twenty-one are in use, is £29 5*s.* each.

The compressed air for driving the fans, and the underground hoisting-engines, is supplied by wet compressors, one of 70 HP. and two of 40 HP.; the initial pressure is 4 atmospheres, and this is diminished by friction in the distributing pipes to very little above 2 atmospheres at the extreme points of the workings. The diameter of these pipes varies from 130 millimetres to 20 millimetres, and of these at the end of 1888 a length of 8,515 metres, or rather more than 5 miles, was in use.

The ventilating-pipes are made of zinc, 26 millimetres in diameter, with sockets 200 millimetres deep at one end of each length. The joints are made air-tight with a mixture of 5 parts of cement, 6 of tar, and 6 of coal dust, the last lengths being put in loose so that they can be taken away for blasting in the end.

The fans are in charge of a special engineman, and to prevent their being tampered with by unauthorized persons, they are enclosed by lattice-work doors which are kept locked, and are only accessible to the engineman who has the key. In addition to relieving the main air-current the ventilation by this method is much better than when parallel drifts and brattices are used. From the high velocity with which the air is delivered, the current is felt even at a distance of 6 to 8 metres from the end of the blast-pipe, and allows any gas given out in the working place to be swept away at once without having the chance of accumulating, which is a point of considerable importance. Another advantage is found in the rapid dispersal of smoke in the end after blasting, and the temperature is lowered from 9° to 10° Fahrenheit. This latter effect is only apparent in the immediate face of the working, and is not perceptible 10 or 12 metres back.

In the twenty-four ventilators in use, the length of pipe between the fan and the point of delivery varies from 14 to 268 metres, the number of revolutions from 189 to 435, and the volume delivered from 5·10 to 20·5 cubic metres per minute, the latter being from about one-third to one-half of that measured on the intake. The loss is partly due to leakage at the joints of the pipes, and partly to the resistance caused by bends. In the most unfavourable condition it is possible to supply 5·10 cubic metres of air per minute at a distance of 270 metres from the fan, or sufficient for two men at work, and by increasing the number of revolutions to 500, the supply may be increased to 6 cubic metres, or enough for three men.

As regards the cost, the following comparative figures are given as representing the outlay in different parts of the mine upon

several lengths of 200 metres of main drift by various systems of working.[1]

	£	s.
I. Ventilation by parallel-drifts and stoppings . . .	168	0
II. Ventilation by brick brattice in the drift	41	10
III. Ventilation by a free standing channel, walled on three sides as required in ground subject to great pressure.	78	2
IV. Ventilation by fans and pipes		

The working cost of the three compressors in 1888 for 8784 hours was £2389 16*s.*

The net discharge of the three compressors is 226·58 cubic metres per hour, and the cost of 1 cubic metre at 4 atmospheres pressure 2·39 pfennige (0·288*d.*).

The time required for driving 200 metres of level is about five months, in which time a fan going 7½ cubic metres per hour will deliver 27,000 cubic metres.

	£	s.
27,000 cubic metres of air	32	5
200 metres of pipes (can be used four times)	9	4
One-thirtieth part of 5 per cent. interest and sinking fund on compressor plant for 5 months	1	17
10 per cent. on cost of fan for 5 months	1	5
	44	11

Although these figures are only approximate it is clear that the most expensive system is that with parallel drifts, and although the brick brattice is somewhat cheaper than the fan, the saving is only apparent, as no account is taken of the extra cost in working the main fan at the surface caused by its use. The fan, therefore, is probably the cheapest, besides having notable practical advantages.

H. B.

On a Capell Fan at Berge-Borbeck. By M. Kattwinkel.

(Zeitschrift fuer das Berg-, Huetten- und Salinen-Wesen, 1890, p. 347.)

At the Prosper I. coal-mine near Berge-Borbeck in Westphalia, where about a thousand miners are employed, the ventilation was originally effected by a Guibal fan 39 feet in diameter, whose maximum capacity was about 76,000 cubic feet per minute at 3·2 inches water-gauge, measured in the air-way at the surface. This being insufficient to meet the extended requirements of the mine, a new ventilator on Capell's patent has been erected, and after a few months' working shows most astonishing results.

The new fan, which was built at the engine works of R. W.

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[1] The details of the items included in these amounts are given in the original.

Dinnendahl, near Steele, is 12·3 feet in diameter and 6·6 feet broad, with a 6·9 feet suction passage on either side, the construction being generally similar to the smaller fan of the same pattern, figure on plate xxv. of the same volume. It is driven by a pair of couple-engines with cylinders 20·5 inches in diameter and 31·5 inches stroke. The piston-rods are 3 inches and 2·4 inches in diameter respectively, giving an average useful piston surface of 324 square inches. The expansion is regulated by a Rider governor fitted to each cylinder, and the power is transmitted by a camel-hair belt 25·6 inches broad, the fan making four revolutions to one of the engine's.

On the 15th of July 1890, working trials of the fan were made by Mr. Herbst of the Bochum Mining School, both at ordinary and maximum speeds. For the former the governors were adjusted for 72 revolutions per minute, while for the latter the governors were thrown off and the engines were worked with full steam admission.

1. Trial at 72 revolutions. The number of revolutions, as well as the water-gauge, were observed continuously. The air was measured in the rise workings of the 234-metre level and in the fan drift at the surface, the observations being carried on for some time in order to minimize the stopping and time errors. Two anemometers were used; they were supported on laths crossing the air-way both above and below ground, the points of observation being symmetrical to each other in both sections.

The result of the underground observations gave a mean velocity $c = 485$ metres per minute for periods of nine or eleven minutes, the sections of the drift being 4·704 square metres, corresponding to a volume of 2,281·4 cubic metres per minute, about 80,000 cubic feet.

The surface measurements gave the velocity for two observations during sixteen and six minutes respectively as 546 metres, which for the section of the fan-drift 5·474 square metres gave a volume of 2,989 cubic metres (nearly 105,000 cubic feet) of air exhausted per minute.

A comparison of these quantities shows that only 76·3 per cent. of the work done by the fan is utilized in the mine, or nearly one-fourth of the steam-power is wasted; this is due to the leaky state of the brattices in the shaft.

The water-gauge at 72 revolutions of the engines was 186 millimetres (7·3 inches), whence the useful effect of the fan, having regard to the *vis viva* of the inflowing gases, is—

$$N n = 122 \cdot 73 - 3 \cdot 44 = 119 \cdot 29 \text{ HP.}$$

For the determination of the indicated HP. fourteen cards were taken which agreed fairly well together; the mean steam-pressure corresponded to 2·144 kilograms per square centimetre, and the total power of the engine, to—

$$N i = 229 \cdot 23 \text{ HP.}$$

$$100\,\frac{N\,n}{N\,i} = 52{,}039 \text{ per cent.},$$

or 5 per cent. better than the best of the fans examined and reported upon by the Prussian Fire-damp Commission. The cut-off in the right-hand cylinder was at about 0·28, and in the left-hand one between 0·3 and 0·4 of the stroke.

In the full-speed trials indicator cards were taken on the left-hand engine when running at 87½ revolutions per minute, but the anemometer observations failed, owing to the strong draught which blew the lamps out; the actual volume of air moved may, however, be estimated with tolerable accuracy. A subsequent attempt to take cards from the right-hand engine at the same speed also failed, the steam-supply being only sufficient for 80 revolutions, at which speed the diagrams were taken. As these are very similar for both cylinders, the following results have been adopted:—

Right engine, 80 revolutions observed, 31·51 millimetres pressure,
87·5 revolutions established, 35·79.
Left engine, 80 revolutions established, 31·15 millimetres pressure,
87·5 revolutions observed, 35·38.

From these the indicated power is compiled to be—

At 80 revolutions	310 HP.
At 87·5 „	390 HP.

the corresponding water-gauge depressions being 223 and 269 millimetres.

The volume of air moved may easily be calculated as being proportional either to the square root of the observed depression or to the number of revolutions. Taking the quantities obtained in the first trial at 72 revolutions as a standard, the volume exhausted at 80 revolutions will be—

$$\text{either } 2989\sqrt{\frac{223}{186}} = 3273 \text{ cubic metres,}$$

$$\text{or } 2989\sqrt{\frac{80}{72}} = 3321 \text{ cubic metres,}$$

or their mean 3297 cubic metres; and at 87·5 revolutions,

$$2989\sqrt{\frac{269}{186}} = 3595,$$

$$\text{or } 2989\sqrt{\frac{875}{72}} = 3663,$$

or a mean 3614 cubic metres.

The effective work of the fan is therefore 157·9 and 207·8 HP. at these speeds, or 51 to 53 per cent. of the indicated HP. The equivalent opening of the mine (Murgue's figure) is calculated at 0·9132 square metre for rounded, or 1·405 square metre, considered as a square-edged aperture. Although this corresponds to a mine of more than medium width, the high-water gauge, together with the large volume of air exhausted, shows a duty which has not been hitherto recorded even approximately in any ventilation trials made by the Prussian Commission. The nearest to it was a Guibal fan at New-Iserlohn, which, however, was only of 49 HP. as against 208 HP. in the Capell fan. As compared with the 39-foot Guibal fan at the same pit, the duty is 7·6 (*sic*) times as large.

In conclusion, the Author calls attention to the lubrication of the fan axle, which is effected by kidney fat broken small in the oil-boxes, and a stream of water kept continually falling upon it. Even at the highest speeds the bearings remain perfectly cold, which was not the case previously when oil or tallow was used for lubrication.

H. B.

Lachomette's System of Regenerative Gas-Furnaces at the Perrache Station of the Lyons Gas Company.

By — Moirand.

(Journal des Usines à Gaz, 1890, p. 236.)

Thirty regenerative furnaces on the Lachomette system are being erected at the Perrache station of the Lyons Gas Company. Six similar furnaces were tried last year at the same works, and have been in use since November 1889. The generator in these furnaces is a fire-brick chamber into which the fuel is put through an opening in the top; the fuel is supported on fire-bars, and the height of the combustion zone is limited by a shield so that it is maintained always at the same level, whatever may be the quantity of fuel in the furnace. The waste heat, before passing into the chimney, follows a series of flues, separated by horizontal partitions of specially shaped bricks. The air to be heated is admitted by a damper, and circulates through the partitions in a contrary direction to the waste gases, and combines with the furnace gases at the points of combustion. The arrangement is very durable, no breakages or cracks being produced by the heat, to create a communication between the passages for the air and those for the waste gases. The area of the flues is sufficient to raise the temperature of the secondary air-supply to over 1832° Fahrenheit.

Steam is supplied to the generators from small cast-iron boilers

supplied to these boilers by a siphon tube which allows the water to enter but prevents the escape of the steam. The water is at once converted into steam, which is superheated by passing through the passages, and escapes freely, without pressure, by a tube beneath the furnace bars of the generator. This very simple and effective arrangement ensures perfect regularity in the production of the steam, and consequently in the consumption of the gases. The importance of introducing steam into the generator is known. It serves, in the first place, to break up or hinder the formation of clinkers, and, by its decomposition, it cools the generator and enriches the gases by the formation of a large proportion of hydrogen and carbonic oxide, undiluted by nitrogen from the air.

The apparatus evaporates the water and superheats it to 392° Fahrenheit, by means of the waste heat not required for heating the secondary air-supply, into which only about the half of the total heat in the waste gases can be passed.

The advantages of this furnace are: its great simplicity, the facility with which all parts can be cleaned and examined while working; no smoke or ashes are produced, which is especially advantageous for the preservation of the firebrick materials. The results obtained, both as to labour and heating, are as favourable as with the best known generator furnaces, while the first cost and maintenance are less, and, in proportion to the quantity of gas produced, it is even cheaper than ordinary furnaces. A Lachomette furnace, with eight retorts, costs at Lyons, complete and ready for work, £320, and produces, with six-hour charges, 63,570 cubic feet of gas in twenty-four hours; while an ordinary furnace, with seven retorts, costs £248, and produces 40,615 cubic feet in twenty-four hours. The firing can be done with ordinary labour, one man being easily able to attend to six to eight fires.

Some trials made at the Perrache Station, under the direction of Mr. Godinet, gave the following results:—

No. 1.—Six Days' Trials with Six Furnaces.

	Lbs.	
"Blanzy" coal used	80,424	
Fuel, coke	8,368	
„ breeze blocks	4,656	
	13,024	
Cinders removed	659	
Fuel employed	12,365	= 15·3 per cent.
Ashes removed	2,762	
	9,603	= 11·9 per cent.

No. 2.—Six Days' Trials with Six Furnaces.

	Lbs.	
"Blanzy" coal used	80,424	
Fuel, coke	7,533	
„ breeze blocks	4,656	
	12,189	= 15·1 per cent.
(*The cinders were returned to the generator.*)		
Ashes removed	2,279	
Fuel used	9,910	= 12·3 per cent.

No. 3.—Six Days' Trials with Six Furnaces.

	Lbs.	
"Blanzy" coal used	73,964	
Fuel, coke	8,027	
„ breeze blocks	2,328	
	10,355	
Cinders removed	516	
	9,839	= 13·3 per cent.
Ashes removed	1,969	
Fuel used	7,870	= 10·6 per cent.

In trials Nos. 1 and 2 the fuel consisted of 60 parts coke, and 40 parts (*sic*) breeze blocks, which partly obstructed the furnace bars and necessitated a strong draught and a vacuum in the furnaces.

In trial No. 3 the charges were smaller, and the fuel used consisted of 75 parts coke and 25 (*sic*) parts breeze blocks; the draught was less, and the combustion in the furnace was under pressure. This working is more favourable, and shows a marked decrease in the fuel used.

C. G.

A Calorimetric Study of the New Siemens Furnace.

By G. Despret.

(Revue Universelle des Mines et de la Métallurgie, vol. xi., 1890, p. 246.)

The Author, after noticing the modifications in the construction of the Siemens heating-furnace from the original form with the siphon cooling-tube, to that improved by Messrs. Biedermann and Harvey in 1889, in which the current of spent gas is partly returned to the producer and regenerated as combustible gas, gives the following analyses of the reactions, and the transfer of heat involved in the working.

The average composition (A) of the gas from producers worked by blast may be taken to be as follows:—

Carbonic acid	8·8
Carbonic oxide.	26·1
Marsh gas	2·8
Hydrogen	1·0
Nitrogen	61·3
	100·0

For complete combustion the following quantities of oxygen are required:—

8·8 CO_2				0·00
26·1 CO	produce	35·6 CO_2	with	9·5 oxygen.
2·8 CH_4	„	7·7 „	„	5·6
		6·3 H_2O	„	5·6
1·0 H	„	9·0 H_2O	„	8·0
				28·7

which quantity, together with 100·5 of nitrogen, is contained in 129·2 of air.

The composition (B) of the burnt gases will be:—

52·1 CO_2	containing	37·9	oxygen.
15·3 H_2O	„	13·6	„
161·8 N	„	0·0	„
229·2		51·5	

On the other side the combustible gases contain:—

8·8 CO_2	with	6·6
26·1 CO	„	15·0
		21·6 of oxygen.

If, therefore, the oxygen (21·6) required in the producer is to be furnished by the spent gases, 21·6/51·5, or 42 per cent. of their weight will be appropriated, leaving 58 per cent. for heating the chequer work in the air regenerator.

The combustion of 100 of gas requires 129·20 of air, and an equal weight of spent gas must be passed through the regenerator to heat it properly. This quantity is 56·5 per cent. of the total weight of burnt gas, so that a margin of 1½ per cent. is left to meet the loss by radiation from the regenerator walls.

The quantity of 42 per cent. is a theoretical maximum; practically less will b required, because a certain part of the oxygen is supplied by the steam of the injector jet, and part of the gaseous products are given off by the materials heated in the furnace.

Passing to the consideration of the reactions in the producer. It is required to convert spent gas of the composition B into

producer gas of the composition A, the thermal requirements for the decomposition being as follows.

The presence of carbonic acid in the gas shows that the reactions and decompositions are not absolutely complete, for out of the total weight of 29·1 kilograms of this gas injected 8·8 kilograms pass through the incandescent fuel without change, the remainder 13·1 kilograms being transformed into 16·7 kilograms of carbonic oxide, with an absorption of heat of 13·1 × 1330 = 17,423 calories.

The remaining quantity of carbonic oxide (9·4 kilograms) results from the imperfect combustion of 4 kilograms of carbon by 5·4 kilograms of oxygen derived from the decomposition of water vapour, which combustion is attended with the development of 4 × 5607 = 22,428 calories, while the heat absorbed is $\frac{1}{9}$ × 6·4 × 29,000 = 20,622 calories. There is therefore a consumption of heat in the producer of 17,423 + 20,622 − 22,428 = 15,617 calories, which must be restored by that of the spent gases.

Supposing the latter to leave the furnace at 1500° Centigrade, the quantity of heat contained will be :—

CO_2	21·9 × 1500 × 0·217 =	7,128
H_2O	6·4 × 1500 × 0·475 =	4,560
N	68·0 × 1500 × 0·245 =	28,050
		38,738

The burnt gases therefore bring back to the producer an amount of heat which, after restoring the 15,617 calories required for the transformation, leaves 23,131 calories available for heating the regenerated gases, whose temperature may be computed from their specific heat; the calorific value per 100 degrees of sensible heat being:—

CO_2	8·8 × 100 × 0·217 =	190·96
CO	26·1 × 100 × 0·245 =	639·45
CH_4	2·8 × 100 × 0·593 =	166·04
H	1·0 × 100 × 3·409 =	340·90
N	68·0 × 100 × 0·245 =	1501·85
		2839·20

As there are 23,131 calories disposable, it appears that the sensible heat of the gases leaving the producer may be 814° Centigrade, a temperature which is not attained by the older producers in ordinary working.

As regards the economy of the new system the following points may be derived from the study of the figures given above.

1. The 21·9 kilograms of carbonic acid blown into the producer contains 6 kilograms of carbon capable of regeneration, and the combustible gas contains 15·7 kilograms total carbon. Therefore 6 out of 15·7 kilograms, or 38 per cent. of the combustible, is supplied free of cost.

available heat of the two constituents CO and H being 53,942 calories out of 123,875 obtainable from the producer gas, or an economy of 43 per cent.

In the old system the spent gases, after passing the gas regenerator, escaped to the chimney at a temperature of about 300° Centigrade, carrying off an amount of heat which is utilized when the gases go back hot to the producer. This economy the Author considers to be 7,748 calories, or about 6¼ per cent. of the total amount of 123,875 calories. The saving in fuel also leads to a saving in wages for attendance and firing, and together these may be put at 50 per cent., besides numerous minor advantages. When a non-oxidizing flame is required a considerable proportion of carbonic oxide passes through the furnace unburnt, and in the ordinary way is lost in the chimney, but by the new system the unburnt gas goes back to the producer, and is saved for further work.

In glass-making a further economy may be realized from the carbonic acid given off by the limestone in the charge. This for an ordinary lime-and-soda glass gives gases containing 53·8 kilograms of CO_2, instead of 51·5 kilograms per cent. as previously calculated, and therefore a smaller proportion of these will be sufficient to effect the regeneration. This is calculated as 40 instead of 42 per cent., or a saving of 2/42, or 4·7 per cent. If the alkali is used as carbonate the calculated saving in the same manner as 3/43, or 7·1 per cent.

Of course the proportion of carbonic acid in the gas to be regenerated cannot be increased indefinitely as the real restorer of the heat is the nitrogen in the mixture, and consequently as this diminishes the heat brought back is similarly reduced; but within the limits given above the Author considers that the gas may be supplied from the producer at a temperature of about 700° Centigrade.

H. B.

On the Magnetic Separation of Iron from Ores of other Metals.

By G. Prus.

(Le Génie Civil, vol. xvii., 1890, p. 337. 1 Plate, 1 Fig.)

The Author states that almost all ores of the carbonates or oxides are accompanied by ferruginous gangues which do not injuriously affect them as far as reduction is concerned, but add to the cost of carriage and treatment. If the pieces are of fair size, hand-picking is the cheapest method, but usually the mixture is intimate. Mechanical methods are useless, as the iron compound weighs about as much as the ore; this is specially the case with carbonate and silicate of zinc, of which the present

Paper treats, and magnetism is used to free the ore from oxide of iron. The details are supplied by Mr. Charles Vial, Engineer of the Mercadal mines, Santander, Spain, where the plant has been used very successfully. The ore occurs in beds of clay containing limestone and oxide of iron, and contains only 12·13 per cent. of metallic zinc. After treatment, the contained zinc reaches 50 per cent. Pieces which are over half an inch in section each way are hand-picked, all the rest is calcined in furnaces. The iron is all present as $Fe_2 O_3$; this has to be changed to $Fe_3 O_4$, and is done during calcination by admixture of a little coal. After calcination, the products are passed through sieves, and all but the dust goes to the Siemens magnetic separator, which takes out all the iron; this machine consists of a cylinder 17·7 inches diameter and 30 inches long, carried on four rollers, which give it a rotary movement. The outside of the cylinders is made of forty rings of soft iron, separated by gun-metal rings of a less height, the conductor of the electric current is wrapped round the cylinder in the annular spaces; at the end where the metal enters, only two coils are used, and the number is increased to the other end, so as to distribute the work done equally. The current is led to a copper brush, which rubs on a gun-metal ring, insulated from the shaft. Inside the cylinder is a gun-metal scraper fixed to a central tube containing an Archimedian screw. The ore is fed into a hopper, and falls into the revolving cylinder, the particles of iron are attracted to the inner surface, and carried up to the top, where they are scraped off by a knife, and falling into the tube, are carried away by the Archimedian screw. Quantities up to a ton an hour can be treated by this machine, and from 65 to 70 per cent. of the iron taken out.

Another type of magnetic separator, known as the Kessler, is also used. In this machine a central hollow cylinder of soft-iron is used, which is magnetically excited by a bobbin in the middle; the cylinder acts as a pulley, round which are passed belts supporting short pieces of iron like spikes, which become magnetized by induction; these pass through the ore as it descends, and attract and hold the particles of iron until they lose their magnetic power by passing out of the range of induction of the cylinder, the particles then drop away into a hopper.

The ore-dust proceeding from the sifting process is separately heated in another machine designed by Mr. Vial; this dust contains 15 to 35 per cent. of zinc, and from 20 to 40 per cent. of iron; from this is obtained a product containing from 45 to 53 per cent. of zinc, and about 8 to 15 per cent. of zinc is lost.

A portable engine of 4 HP. is used. The dynamo is one of Siemens D 7 type, with a copper conductor 0·137 inch diameter. A cable 0·2 inch outside diameter, and formed of seven copper wires, carries the current to the separator. An arrangement of cone pulleys is used for varying the speed of the dynamo to suit the degrees of coarseness of the ore under treatment.

Results.—The results are the more satisfactory the greater is

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Taking as ordinates the differences between the successive dilatation of the bar at temperatures differing by 5° Centigrade, and for abscissas the mean of these temperatures, curves were constructed showing the values of the coefficient of dilatation.

From an examination of these curves the Author observes that the differences of dilatation decrease very rapidly when the temperature falls below − 30° Centigrade, and tend towards zero between −100° and −150° Centigrade, and he thinks that beyond −100° the contractions of steel are no longer appreciable under an increase of cold.

The second part of the investigation is to determine the effect of great cold upon the tensile force of steel.

After describing the test bars, the apparatus, and the precautions taken to avoid errors of experiments, the Author gives the results in tables containing for the temperatures used :—

1. The elastic limit in kilograms per square millimetre.
2. Change of rupture.
3. Elongation per cent.
4. The striction at rupture.

From these Tables the Author concludes :—

1. That the elastic limit and the charge of rupture both increase with the low temperature as well for tempered as for untempered steel.
2. The elongation decreases with the temperature.
3. The striction also diminishes with the temperature.

The following are the approximate results in passing from a temperature of about 12½° Centigrade to −70° Centigrade :—

Elastic limit	increases	untempered	from	1·0 to 1·11.
		tempered	„	1·0 to 1·113.
Rupture	increases	untempered	„	1·0 to 1·03.
		tempered	„	1·0 to 1·06.
Elongation	decreases	untempered	„	1·12 to 1·0.
		tempered	„	1·14 to 1·0.

The Author next enquires whether steel sustains any permanent injury by subjection to these severe colds. The result was, that such modifications as it undergoes under such circumstances disappear altogether when the metal returns to its ordinary temperature.

The last part of the investigation was to ascertain the effect of very low temperatures in respect of the resistance to transverse shock. The bars used were 0·787 inch square and 4 feet 1 inch long, and were cut from hoops of gun steel made at Firminy. The tempered bars were hardened in water at a bright cherry red, and afterwards annealed from a dull red heat.

The full description of the apparatus and method of using it is given with detailed tables of the results.

The temperature was as before about −70° Centigrade to −75° Centigrade; and the following is a summary of the conclusions :—

The tempered bars withstood on an average 17 blows at ordinary temperature and 12·6 at the low temperature.

2. A comparison between the tempered and untempered bars shows that under the action of the cold the fragility of the untempered bars increases in a large proportion.

3. The stiffness increases as the temperature diminishes.

Summary of Results.

Under the influence of severe cold the molecular state of steel is modified temporarily as follows:—

The elastic limit, the breaking load, the hardness and the stiffness increases as the temperature diminishes.

The fragility under shock also increases.

The elongation decreases.

These modifications have not a permanent character, and the metal returns to its original state under the ordinary temperature.

J. A. L.

Researches in Thermo-Electricity.

By — Chassagny and H. Abraham.

(Comptes rendus de l'Académie des Sciences, Paris, vol. cxi. 1890, p. 733.)

By suitable construction of the galvanometer thermo-elements can be made to give readings accurate to 1 in 10,000; or between 0° and 100° Centigrade to one-hundredth of a degree. The Authors have by careful experiment determined the following empirical ormula for the indication of a copper-iron couple in degrees of the hydrogen thermometer:—

$$E_0^t = \frac{at + bt^2 + ct^3}{t + 273}$$

$$\text{where } a = 10^{-3} \times 3{\cdot}56604$$
$$b = 10^{-6} \times 8{\cdot}3827$$
$$c = 10^{-8} \times 3{\cdot}265$$

t and o being the temperature of the two junctions; and the maximum error not exceeding one-fiftieth of a degree.

F. J.

Variations of Conductivity under Electrical Influences.

By EDOUARD BRANLY.

(Comptes rendus de l'Académie des Sciences, Paris, vol. cxi., 1890, p. 785.)

If a very thin layer of copper dust be placed on a matte surface of glass or ebonite and burnished, its resistance, for the same weight of metal, may vary from a few ohms to several megohms; the same experience is gained with other metallic powders, enclosed with or without admixture of insulating liquids in insulating tubes; and the effects hereinafter recorded are more marked and more easily produced with these latter.

If now a conductor, so formed, and presenting a high resistance to a low electromotive force, be placed in the neighbourhood of an electric spark, excited for instance by a Wimshurst machine, or a Ruhmkorff coil, the resistance is suddenly reduced to a very considerable extent, such reduction being, however, not momentary but persisting in instances for more than twenty-four hours; but the subsequent history of such a film when left to itself has not yet been completely investigated.

It is not necessary that the circuit should be closed when subjected to the influence of the spark, though the effect is then not so marked, while the distance of the spark may also be very considerable, and screens and walls may be interposed. A similar reduction of resistance can be observed by sending through the film an induced current, or a current from a much higher electromotive force; and in this case the resistance is observed to fall a certain amount after each transmission of the current.

F. J.

On the Electrical Resistance of Bismuth in a Magnetic Field.

By A. LEDUC.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxi. 1890, p. 737.)

The Author has determined for various specimens of bismuth both the variation of resistance due to temperature alone, and that due to the influence of the magnetic field at various temperatures. Each specimen had its own special rate of change with temperature which could be satisfied for any given specimen, by certain coefficients in an expression containing power of the temperature up to the third, and as regards the magnetic field, its effect also varied with the temperature; so that the final expression for the change of resistance in a magnetic field is somewhat complicated.

For all practical purposes the change for any given specimen can be determined by four observations, viz., at two temperatures and in two known fields; and for small differences from the mean temperature of say 60° Fahrenheit the value can be expressed

For a certain specimen the Author gives for the coefficients of the following formula :—

$$Z^2 + 2\,b\,Z - a\,M^2 = 0,$$

where Z is the increase of resistance per unit expressed in thousandths, and M the intensity of the magnetic field,

$$a = 0\cdot00231\;(1 - 0\cdot0153\,\overline{t - 15})$$
$$b = \quad 131\;(1 + 0\cdot0011\,\overline{t - 15})$$

t being expressed in degrees Centigrade.

F. J.

On the Influence of Potential on Cable-Insulation. By C. Heim.

(Elektrotechnische Zeitschrift, 1890, pp. 469 *et seq.*)

The Author observes that as electric installations are increasing in size and number, and as the tendency is always to use higher potentials, whether with direct or alternating currents, that it is necessary to give more attention than ever to the insulation. It was first pointed out by Uppenborn that the insulation of an installation is not independent of the potential, but decreases as the latter increases. Cables are now used to carry higher potentials, the three-wire system has 250 volts between the outer wires, and the five-wire system has 500 volts.

It appears probable that the effects observed with the alternating current in which yet higher pressures are being used, are similar to those found with the direct current. Cables are in use with 2000 volts pressure for alternating currents. Therefore the enquiry into the possible changes in the insulation from high potential is of great interest, especially as tests of that kind are calculated to give information as to whether cables carrying direct currents of high tension would remain good for long periods.

For the more insulation resistance decreases with the increase of pressure so much the sooner may it be supposed that the insulating material will change its character from the continual action of the high potential difference. Although the underground telegraph cables work with trifling pressure, it is still important that the relation of insulation resistance to potential should be known. On this account corresponding measurements were made on lead-covered cables, insulated with spun yarn saturated with a mixture of resin or paraffin, as well as on gutta-percha covered wires. Also some experiments of a more tentative character were made with the winding of a dynamo, with an ordinary electric-light cable fastened to the wall, with electric-bell wires, and with a bare conductor on porcelain insulators.

It was seen, with one exception yet to be experimented on, whether the influence of potential difference had different values at different temperatures. The Author has always experimented at a medium house-temperature. After the Author had begun his measurements, Foerderreuther published a test "On Insulation Measurements in Electric-Lighting Cables," which was so closely allied to the objects of his work that it touched upon the subject of influence of potential differences in resistance.

However, Foerderreuther merely dealt with overhead wires, did not consider changes of temperature, and above all only dealt with pressure up to 89 volts.

The test material used by the Author consisted of two bare lead-covered cables 1,090 yards long, and a gutta-percha covered wire about 872 yards long, all lent for the purpose.

The sizes of the lead-covered cables were :—

No. 1.	Copper wire,	0·055 inch diameter,	outside diameter	0·208 inch
No. 2.	„ „	0·043 „	„ „ „	0·134 „

The electrical capacity measured by Thomson's compensation method was for No. 1, 0·137 microfarad at 15·5° Centigrade, and for No. 2, 0·135 microfarad at 15·7° Centigrade, and the cables were compared with a mica-condenser of 1 microfarad capacity.

These cables came from different makers, and therefore probably the insulation was of a different composition. No. 2 was in two pieces. The Author believes that the dimensions stated are quite large enough if the di-electric is the same as with the larger forms. The absolute value of the insulation resistance agreed in both cases when the relation between the diameter of the copper and the outside was equal. The gutta-percha covered cable contained a copper cable of seven wires of about 0·065 inch diameter, and was insulated with two layers of gutta-percha until 0·197 inch outside. This is the usual type in use by the German Post Office. The capacity was 0·190 microfarad at 14·5° Centigrade.

Mode of Measurement.—A Thomson reflecting-galvanometer was used with four shunts, a commutator of vulcanite, a battery with double keys and a rheostat of 100,000 ohms. The relative deviation with the highest of the measured insulation resistances was not more than 1 per cent. of the deviation caused by the insulation current. The battery consisted of 330 small copper elements to which 60 accumulator cells could be coupled, so that from 460 to 470 volts could be used. The copper elements contained on the bottom of glass vessels 5·5 inches high and 2 inches wide, a disk of lead 1·77 inch diameter, to which a gutta-percha covered wire was soldered. About 0·4 inch above this was a zinc plate of similar size with a handle cast on; a zinc strip reached up to the edge of the glass, and the zinc disk was inclined to the horizontal to allow the gas to escape. Such a battery, with a 5 per cent. sulphate of zinc solution, and a small quantity of copper sulphate crystals, gave 1·06 volt after a few days, and at the end

most simply with insulation resistance of the cable in one line corresponding to differences of potential in another, both on a decreasing or increasing scale. There are two objections to this method; one, that the temperature must be kept constant; the other, that time must be allowed between two tests, or else a back pressure is set up which causes deceptive readings. The gutta-percha cable was most carefully shielded from outside changes of temperature; it was put in a barrel filled with water which itself was placed in a wooden box, and surrounded with saw-dust; the ends of the cable passed out through cork into gas-pipes filled with saw-dust and corked up. For the lead cables, barrels of sufficient size were not at hand, so the cables were wrapped in straw and placed in paste-board boxes. Minute details of the methods of measurement are then gone into and the tables of results follow. The various changes in resistance which are caused by various pressures are shown. A table is given of the changes in insulation resistance of the magnet-windings of a dynamo in the cold and warm state, the measurements being taken one minute after closing circuit. This is a long paper continued through three issues of the "Zeitschrift," and concludes with an abstract of Foerderreuther's results in the same direction.

E. R. D.

On the Best Dimensions for Standard Optical Ammeters and Voltmeters. By A. E. Kennelly.

(The Electrical Engineer, New York, vol. x., 1890, pp. 540, 566.)

An optical galvanometer is one in which is utilized the electromagnetic power of the current in rotating a beam of light which passes through a suitable polarizing medium, as, for instance, bisulphide of carbon, which can be obtained readily in a high state of purity, and for which the electro-optic constant has been determined by numerous observers.

The proper amount of copper to be used on an instrument of suitable mechanical dimensions, so as to reduce as far as possible the influence of temperature on the optical constant, is discussed and the formulas enunciated for each description of instrument; and it is shown that the degree of accuracy attainable is at least 1 in 750. Instruments of this type, though not suitable for general use, are especially convenient for standardizing purposes, as the values in absolute measure can be determined by purely geometrical data.

The different formulas given in the Paper have been practically tested as to their reliability by direct experiment in the Edison laboratory, and may be summed up as follows:—The amount of

rotation varies as the square root of the weight of the copper wires, and as the square root of the ratio of length to internal diameter of the helix. The equations for the best size of wire to use, and the correction for virtual length are all fully explained by the Author.

F. J.

The Marès Energy-Meter. By P. Juppont.

(Le Génie Civil, vol. xvii., 1890, p. 306, 16 Figs.)

This apparatus is a watt-hour meter which may be classed as a galvanometer with intermittent integrator. It records at regular intervals, in this case of four minutes each, the number of watts consumed at that instant by the lamps or motors in the circuit. The principle of the apparatus is not new, as it has been employed before by Vernon Boys, Siemens, and others; but the inventor has changed the electro-dynamometer balance of Sir William Thomson into an automatic integrator, which will work for an indefinite period, as the clock which measures the time factor is kept going by a small current of electricity shunted from the main circuit.

The action is as follows: A coil of thick wire is placed in the main circuit, and is stationary, while inside it is hung a shunt coil of fine wire, suspended from the short end of a steelyard, the long end of which carries a movable weight. The distance of the point of suspension of the movable weight from the fulcrum is proportional to the attraction between the two coils, and therefore to the watts being consumed at that instant. It is therefore merely necessary to cause the weight to slide so as to obtain equilibrium, and to take the sum of the distances from the fulcrum at which it has momentarily been in equilibrium. The actual weight consists of a small carriage on rollers, and from it hangs a vessel full of shot to allow of adjustment, and a screw at the end of the steelyard is also provided for the same purpose. The carriage carries a rigid arm in a vertical downward direction, which is jointed to an arm carried by a spindle which also carries a toothed wheel. The toothed wheel rolls inside a wheel of twice its diameter with internal teeth, so that a given point on the circumference of the small wheel describes a hypocycloid which is a straight line; the balance weight is therefore caused to travel in a right line along the steelyard; the larger wheel of the sun and planet motion is caused to revolve by clockwork at a known speed, so that the weight moves from the fulcrum to equilibrium, and back to the fulcrum every four minutes.

In order to obtain the sum of the distances from the fulcrum of the movable weight after each instant of equilibrium, the movable carriage carries a rack which gears into a toothed wheel forming the first of the summation train. The current flows in the shunt coil of the watt-meter during the movement of the

carriage away from the fulcrum, and when the weight passes the position of equilibrium, the steelyard tips and is stopped by an adjustable screw; the teeth of the rack are then clear of the totalizing wheel, the current is switched off the shunt coil, and the carriage returns to the fulcrum without moving the totalizing wheel in a contrary direction. If there be no current flowing in the watt-meter, the movement of the carriage causes the lever to tip before the rack engages with the wheel so that no record is given. The current is switched on and off the shunt coil of the watt-meter by means of a disk which makes a revolution every four minutes, and is provided with a metallic contact strip over half its circumference only, so that the current flows through the coil for two minutes, and then ceases to flow for two minutes more. The spring which works the clockwork moves the ratchet-wheel through a space equal to five teeth in four minutes; and in order to cause it to return, or to re-wind the spring, an electro-magnet is provided which attracts an armature and moves the rachet-wheel back one tooth; this takes place five times in four minutes, the current being switched on and off by five contacts on the rotating commutator previously mentioned.

The spring thus being constantly re-wound is kept at practically the same tension, and as the current only flows through the watt-meter at intervals the coil heats very little. The meter must be placed absolutely horizontal to work properly. Several instruments of this type have been used at the central station at Montpellier, and have given satisfaction, the inventor stating that the readings are within 1 per cent. The instruments there used were made by Dejardin of Paris.

E. R. D.

A Proper Basis for Determining Electric-Motor Rates.

By H. L. Lufkin.

(The Electrical Engineer, New York, vol. x. 1890, p. 214.)

This Paper is illustrated with twenty-nine diagrams, giving the power absorbed during each hour of a working day by electromotors in actual operation for various manufacturing industries and of capacities rated between 2 and 25 HP. The average results obtained from examination of the whole series show average load on motor, 43·75 per cent. of its capacity; maximum load on motor 68·24 per cent. of its capacity; average load on motor 64 per cent. of maximum load.

A cursory consideration of these figures demonstrated that a "maximum-capacity" rate pays the station rather too handsomely for the power actually delivered, and a maximum-load rate would probably be more likely to give satisfaction to all, and at the same time be not too high in competition with charges for gas-engines or similar small motors.

The maximum-capacity rating, further, is a considerable difficulty in the proper choice of a motor, as the customer is governed much more by the charge for current than by the first cost.

Another remarkable feature of these diagrams is that only three-eighths of the power actually used is employed in useful work, five-eighths being consumed in driving the shafting, and this points to the probable use of separate motors directly geared to each machine. Another point demonstrated by the curves is the return of power to the circuit by the descent of elevators, and as such elevators are being largely used, this is a strong argument in favour of a constant potential power circuit as compared with a series circuit.

F. J.

The Trouvé Brygmatoscope.

(Le Génie Civil, vol. xvii., 1890, p. 271, 1 Fig.)

This instrument, invented by Mr. G. Trouvé, is intended for examining the geological strata in bore-holes. It consists of a powerful electric glow-lamp contained in a cylinder, one of the two semi-cylindrical surfaces of which acts as the reflector, while the other, made of thick glass, allows the rays to pass through and light up the surface of the strata. The bottom of the case consists of an elliptical mirror inclined at 45°, and the top is open, so that an observer at the surface provided with a telescope can see the reflection of the bore-hole in the mirror. The lamp is so arranged that vertical rays are intercepted. The apparatus can be let down into the hole by means of a cable composed of two electrical conductors, which is worked by a small crab with insulated metal trunnions. These trunnions are provided with spring rubbing contacts, so arranged that the current from a portable battery can feed the lamp, and still allow it to be raised or lowered at will. It is said that this instrument gives good results at depths of 200 or 300 yards, and that the different strata can be easily identified. As the power of the glow-lamp can be increased, the depth at which observations can be made is only limited by the range of the telescope. The expedition sent by the Portuguese Government to the Mozambique coasts to explore for minerals and coal is provided with this apparatus.

E. R. D.

Metallic Thermometer with Electric Recording-Gear.

(Le Génie Civil, vol. xvii., 1890, p. 300, 5 Figs.)

Mr. Chibout has brought out a very sensitive metallic thermometer, so constructed that readings can be made at any distance. It consists of two distinct apparatus, a transmitter, or thermometer proper, and an electrical receiver. The transmitter can be

receivers, for multiple readings at a distance. It consists of a bar of metal which easily expands, such as zinc in thin plates, but of such a section that it possesses the greatest rigidity possible. This bar is fixed by one end to a marble support, and at the other is joined to the short end of a lever, thus allowing the length of the bar to vary; to the long end of the same lever, and at the same side of it, is fixed another similar bar, and the other extremity of the second bar acts on a similar lever, to the long end of which is fixed a rack-gearing with a small pinion, on the axis of which is carried a pointer working over a dial which registers in degrees the movement caused by the expansion of the two bars. Each joint between an expansion-rod and a lever is made by means of a piece of spring steel, so as to avoid friction and still allow perfect play. The fulcrums of the levers may be fixed on a rigid support of material which is but slightly affected by the temperature, or the support may be reduced to a simple cross-bar, which then carries the one extremity of the first bar, and also the fulcrum of the last lever. Upon the last lever is fixed a radial contact-maker, which moves over a sector consisting of contact pieces insulated from each other, and corresponding to the graduations on the dial of the thermometer, or the contact-maker may be made on the recording needle itself, and in this case the contact-pieces are arranged radially. The contact-maker with each insulated strip forms an electrical circuit for each division on the thermometer dial. Each contact corresponds to a circuit of different power, or to one circuit in which the current can be modified by means of a coil of variable resistance.

The receiver consists of a circular solenoid, in the centre of which is a spindle carrying a pointer travelling over a circular dial. The pointer carries at one end a small piece of soft iron, which, in the normal state, rests against another stationary piece of soft iron. Under the influence of the electric current, which proceeds from a battery through the thermometer proper, the two pieces of soft iron become magnetized with the same polarity and repel one another, and the needle travels through an angle proportional to the intensity of the magnetizing current, so that a record is given on the receiver precisely similar to that on the thermometer dial itself. On the electric circuit a switch is placed in any suitable position, which allows the circuit to be closed, causing the receiver to work. The receiver is practically a voltmeter of special form, and could be used as such; if a thicker wire were used it would serve as an ampere-meter. If the solenoid be made in an elongated elliptical form, and the axis of the pointer be moved to a suitable position, the sensitiveness of the apparatus is increased. The instrument is specially intended for allowing the temperature of distant rooms, where a constant heat must be maintained, to be read in the office.

E. R. D.

The Distribution of Energy in Towns. By F. Uppenborn.

(Elektrotechnische Zeitschrift, vol. xlvi., 1890, p. 605.)

In this article the Author compares various methods of distributing energy in the shape of heat, light, and power. Heat may be distributed by means of high-pressure steam, but the system is uneconomical and dangerous. Coal-gas and Dowson gas are for this purpose less objectionable, especially for industrial purposes, when precautions can be taken against poisoning. As regards the distribution of light, the Author compares petroleum, gas and electricity. The cost of petroleum lighting, assuming that a gallon of petroleum cost 10*d.*, varies between 0·2*d.* and 0·45*d.* per 16 candle-power flame per hour, according to the kind of lamp used. As regards gas lighting, the Author estimates, on the basis of 4*s.* 8*d.* per 1,000 cubic feet, and the figures in the following Table are therefore considerably higher than would be the case with gas at the prices usual in England.

Description of Burner.	Total candle-power.	Cost in Pence per Lamp-hour of 16 Candle-power.
Fishtail . . .	17·2	0·49
Argand . . .	19·4	0·408
Welsbach. . .	10·5	0·324
Siemens No. 3 .	46·9	0·317
Siemens No. 1 .	132·0	0·400
Wenham No. 2 .	44·8	0·186
Wenham No. 4 .	170·0	0·134

In dealing with the cost of electric lighting, the Author points out that the fixed rate of 5*s.* per annum per 16 candle-power lamp customary in Germany, is needlessly high, inasmuch as the price of lamps is only 2*s.* 6*d.*, and their life at least six hundred hours, or about equal to a year's use. In addition to the fixed rate of 5*s.*, the electric lighting companies charge for the current at the average rate of 0·48*d.* per 16 candle-power lamp-hour. Including all charges, the cost per 16 candle-power lamp-hour is at present in Germany as follows:—

Time of lighting from dusk till	Hours per Annum.	Cost of current per lamp-hour.	Total cost per lamp-hour for installations of	
			10 lamps.	100 lamps.
		d.	*d.*	*d.*
6 p.m.	233	0·48	0·82	0·76
8 p.m.	708	0·48	0·59	0·57
10 p.m.	1,425	0·43	0·48	0·48
Midnight.	2,155	0·41	0·45	0·45

the Table.

In dealing with the distribution of energy for power-purposes, the Author considers more particularly the use of coal-gas, Dowson gas, high-pressure water, compressed air and electricity. The Author speaks favourably of the use of gas-engines, especially when worked by Dowson gas, but does not consider high-pressure water an economical agent for the distribution of energy, citing in confirmation of his views the experience gained with the large hydraulic installations at the Frankfort railway station. The use of compressed air he criticises still more adversely. The volume of compressed air required per horse-power hour is, according to the experience gained at Paris, 900 cubic feet for large motors worked by heated air, 1,370 cubic feet if the air is used cold as it crosses from the main, and 2,500 cubic feet for small motors and cold air. These figures refer to the majority of motors now in use, but it is said that an improved type of motor only requires 470 cubic feet of compressed air per horse-power hour. The cost of air is given at 0·114 per cubic metre, or *4d.* per 1,000 cubic feet.

The advantages of electricity for power purposes are: high efficiency, ability of the motor to work overloaded, simplicity, durability, safety and compactness. An electromotor giving 100 brake-HP. occupies a space of only 55 cubic feet. As regards the cost of power, the Author cites Von Mueller's figures, showing that the horse-power hour costs from 0·18*d.* to 0·24*d.* Bearing in mind the low heat-efficiency of the present engines, the Author considers it hopeless to use electricity for heating-purposes.

G. K.

Alternate-Current Distribution. By T. Laffargue.

(L'Electricien, 1890, p. 1058.)

In this article the Author deals with the precautions to be taken in distributing electrical energy by means of high-pressure alternating currents, and more particularly with the insulation of the transformers used in the Municipal Electric Light Station at the Paris Market. The plant used in this installation is of the Ferranti type. The Author found that the insulation resistance of transformers immediately after they leave the manufacturers' works, is often only a few ohms, which he attributes to moisture and wet varnish. The first thing to do is, therefore, to dry the transformer, which is done by short-circuiting the secondary, and feeding the primary circuit with current taken from the 100-volt lighting leads. The transformer is kept in this condition from a week to ten days, during which time it heats up gently and the

insulation improves. The next step is to put the transformer under its full normal load (2,400 volts primary, and 100 volts secondary), and leave it at work for another period of ten days. During a further period of from ten to fourteen days the transformer is kept at work overloaded to a third of its normal output, and the insulation is then finally tested by joining one terminal of the primary and one terminal of the secondary circuit with the 2,400 volt leads. If, after this treatment, the insulation between the two circuits exceeds one megohm the transformer is considered ready to be installed. The following table gives the results of insulation tests made by using a bridge, and a battery of 430 Leclanché cells. The insulation is given in megohms:—

Normal Output in Watts.	Insulation Resistance between		
	Primary and Secondary.	Primary and Frame.	Secondary and Frame.
7,360	3·0	748	786
,,	5·0	760	736
,,	5·71	311	300
,,	10·9	556	538
,,	5·4	416	300
3,680	1·5	662	548
,,	15·0	2,282	2,282
,,	2·55	760	1,056
,,	2·40	1,268	1,050
,,	6·66	326	549
1,840	24·0	935	2,536
,,	8·0	2,853	2,850

The Author thinks that the large discrepancies between the above figures is due to more or less perfect drying. The transformers when installed are carefully insulated from earth; but the Author is not prepared at present to give an opinion on the question whether an automatic earthing device for the secondary is of advantage.

G. K.

The Flow of Current through an Electric Arc. By H. Luggin.

(Repertorium der Physik, 1890, p. 517.)

This Paper contains a minute description of experiments made by the Author to determine the laws which govern the flow of current across an electric arc between carbon-points. Referring to the anode, he distinguishes two kinds of discharges, the one taking place from the crater with considerable current density, and the other from the surrounding rim with a smaller current density, and at lower temperature. The variation of potential

between these two zones, as found by test-pencils inserted horizontally, amounted to 3 volts, the absolute value of the potential being highest in the centre of the crater, and lowest opposite the point of the kathode, so that the horizontal variations of potential would be positive in the upper, and negative in the lower portion of the arc, being zero about half way between the electrodes. The vertical variation of potential was also investigated by means of test-pencils inserted at different points. When the point of the test-pencil (a carbon rod 1·3 millimetre diameter) was placed well within the crater, the mean potential difference between the luminous surface of the anode and the layer of hot gases immediately contiguous to it, was found from a mean of five observations to be 33·7 volts, with a possible error of $\pm 0 \cdot 47$ volt. The corresponding value at the kathode was found from six observations as 8·78 volts, with a possible error of $\pm 0 \cdot 17$ volt, whereas Uppenborn had previously determined the potential differences as 32·5 and 5·2 volts. According to the Author's estimate, that part of the potential differences between the electrodes, which is caused by the transition from the solid to the gaseous conductor, and is therefore independent of the length of arc, amounts to 42·5 volts, which is the sum of the values above given. The difference between these values is $E = 24 \cdot 9$ volts, and might be taken as a measure of the want of symmetry in the distribution of the potential between the electrodes. The value of E has also been determined by placing the test-pencil midway between the electrodes, and comparing its potential difference with either; if the potential within the arc itself decreases gradually, the value of E thus found should be independent of the length of the arc, and of the total potential difference. The Author found that when the total potential differences between the electrodes was varied from 49·4 to 65·2 volts, the value of E varied from 24·5 to 25·6 volts, but only for solid carbons. For cored carbons the variation was considerably greater. The experiments were made with currents up to 20 amperes, and electrodes of sufficient size in each case to prevent the arc from hissing. A series of experiments was made to determine the hissing point, which the Author found is reached when the current density exceeds about ½ ampere per square millimetre of crater surface. For hissing arcs the potential difference between the anode surface and the layer of hot gases next to it is greater, but it does not increase in proportion with the current density, and it would therefore be incorrect to ascribe this potential difference to the existence of a constant resistance. Although this consideration would naturally lead to the assumption that the arc is the seat of a counter-electromotive force, the Author has failed to detect the slightest polarization of the electrodes after the current was interrupted. By carefully-contrived mechanism he was able to make connection between the electrodes and a delicate electrometer within the 0·005 part of a second after cutting off the current, and yet not a trace of charge could be detected in the electrometer needle. The Author does, therefore, not believe

it possible that the arc can be the seat of a counter-electromotive force of 40 volts as suggested by Dub in the Centralblatt fuer Elektrotechnik, vol. x., 1888.

G. K.

On the Theory of Compound Winding for Constant Potential.

By Dr. Louis Bell.

(The Electrical Engineer, New York, 1890, vol. x., p. 593.)

The Author starts with the data of a properly wound shunt machine, and considers the series coils, which must be added, as consisting of three parts (a, b, c), which together introduce the necessary correction for the defects of the simple shunt machine. The first part is added to counteract the loss due to the resistance of the armature, and therefore increases the induction proportionately to such loss; as, however, the permeability of the iron will be different for this increased induction, series winding must be increased to compensate for this alteration in permeability in the ratio of the permeability at the two stages of open circuit and full load. Calling this number of turns a, then—

$$a = \frac{N r}{R} p,$$

where N and R are the number and resistance of the shunt-coils, r the resistance of the armature plus series coils, and p the ratio of the permeability above mentioned, and which in practice will have a value between 1·05 and 1·5.

Now since by adding the series coils the magnetic resistance has been increased, the magnetizing effect of the shunt-coils will be thereby diminished, and there must be added to the series coils a further number of turns given by the formula

$$= \frac{N E}{R C}(p - 1)$$

E being the electromotive force on open circuit; C the current in the external circuit on full load.

It will be noticed that p occurs in each of the above formulas, and the Author shows how this quantity can be readily determined from the characteristic of the given shunt-machine, or from the permeability curve of the iron employed.

The last addition of series turns, c, is demanded by the alteration in the demagnetising effect of the armature at full load, and this is given by

$$C = v\, m \frac{l}{\pi}$$

where m is the number of convolutions in the armature, and l the angle of lead.

The three terms above given constitute, therefore, the requirements of the series-coils, and the values given by these equations are calculated and compared with the actual values in certain specified machines.

It is evident, however, that the compounding cannot be absolutely perfect for all loads, and a great deal can be done by a proper design of pole extremities to the electro-magnets.

F. J.

The Magneto-Optical Generation of Electricity.

By Samuel Sheldon, Ph.D.

(American Journal of Science, September 1890, p. 196.)

It is well known that if a beam of plane-polarized light be passed through a tube containing bisulphide of carbon, and if the tube and the beam lie in the direction of the lines of force of an electro-magnet, the plane of polarization of the emergent beam will be rotated upon exciting the magnet, the direction and amount of the rotation depending respectively on the direction and strength of the current. The Author desired to ascertain if on reversing the conditions of the experiment, and causing the plane of polarization of the light to rotate rapidly, an inverse difference of potential would be produced between the terminals of the coil, a continuous current being caused by continuous rotation, and an alternate current by an oscillation of the plane of polarization. The latter supposition was verified by the Author's experiments.

The coil employed was wound upon a thin brass tube, closed at each end by a plate of glass, and filled with bisulphide of carbon. The length of the tube was 175 millimetres (6·9 inches), and its diameter 23 millimetres (0·91 inch). The coil was made of wire 0·085 millimetre (0·0035 inch) diameter, and was 150 millimetres (5·91 inches) long, and 45 millimetres (1·77 inch) diameter, the resistance being 7·21 ohms. It was found that with this apparatus a current of 1 ampere produced a rotation of the plane of polarization of 78 minutes. The Author calculated that the electromotive force produced by causing the polarizing nicol to revolve two hundred times a second would be, with the apparatus employed, far too small to be detected by the galvanometer, and he therefore made use of the extreme delicacy of the telephone as a substitute, and an oscillation of the plane of polarization instead of a revolution. The arrangement of the apparatus was as follows:—Light from an arc-lamp, after passing through a large nicol, was reflected at a very obtuse angle from a small mirror fixed in a brass frame, free to rotate about an axis nearly parallel with the ray of light. This mirror, by which the light was reflected through the tube containing the bisulphide of carbon, was made, by a suitable mechanical arrangement, to oscillate through 45° about three hundred times a second. The plane of polarization was thus twisted

through twice that amount, or 90°, during each oscillation. The terminals of the coil were connected with a telephone, placed in a room in a distant part of the building.

While the mirror was being made to oscillate, the experimenter could easily distinguish a note by placing an ear at the telephone, but this note was the octave above that given by the vibrating mirror. When the circuit was broken the sound ceased, but upon again closing the circuit the note became audible. With a rate of two hundred oscillations per second the note was not so easily distinguished.

G. J. B.

A Mountain Magnetometer. By Oskar Emil Meyer.

(Annalen der Physik und Chemie, 1890, p. 489.)

The magnetism of masses of rock within a mountain can be ascertained by observing the disturbance produced upon the uniform magnetic field of the earth, and several instruments have been constructed to measure this disturbance. A simple apparatus is the so-called Variometer of Kohlrausch, which consists of a compass-needle, and a magnet pivoted below it on a vertical axis. If the magnet is placed in the magnetic meridian with its north-pole pointing north, the needle also places itself into the meridian, but with its north pole pointing south, since the field of the magnet is stronger than that of the earth. If, now, the magnet be turned through a definite angle, the needle will be deflected under the joint influence of the two fields, and by observing these two angles it is possible to determine the local horizontal component of the earth's magnetic field.

This instrument alone is, however, insufficient for the determination of the magnetism within mountains, because the variation of the horizontal component, which it alone indicates, may be due to either a variation of the total intensity, or to a change in the inclination. To eliminate this cause of error it would, therefore, be necessary to alter the construction of the instrument so that it may also be used for the measurement of the local vertical component of the earth's magnetism; but the Author has found a still simpler solution of the problem by arranging the apparatus in such way as to measure directly the variation in the total intensity of the earth's field at the place of observation (the side or top of a mountain), as compared with its average value in the district. The compass-needle is pivoted on a horizontal axis, and in the same line, east or west of it, is pivoted the magnet. The magnet is placed parallel to the lines of the earth's field, with its north pole downwards, when the north pole of the needle will point upwards. The magnet is then turned, and the angle of deflection of the needle observed, in the same way as in the original instrument of Kohlrausch.

where magnetic rocks exist in a mountain, the increase in the horizontal component of the intensity is considerable; from which he concludes that the magnetic axes of such masses are more or less parallel with the direction shown by an inclination needle, the north poles of the masses being below, and the south poles above, in the northern hemisphere. The Author next proceeds to describe the construction of the instrument, and the methods of its use, including certain precautions for the exact alignment east and west of its axis, and the elimination of errors; after which he gives a complete theory, and an account of observations taken in various localities in Prussian Silesia.

G. K.

Self-Induction and Capacity. By P. Boucherot.

(L'Electricien, 1890, p. 102.)

The interaction between self-induction and electrostatic capacity may cause heavy strains on the insulation of cables in alternate current work, and the subject of the Paper is therefore one of considerable importance to the electrical engineer. The Author takes as the basis of his investigation the well-known sine law, according to which the electromotive force at any moment is given by $e = E \sin w t$, where E is the maximum value of electromotive force, or crest of the wave, and $\omega = \frac{2\pi}{T}$, T being the periodic time. The counter electromotive force due to a self-induction whose coefficient is L, is $L \frac{d i}{d t}$, where i is the current, and the relation connecting the electromotive force between the plates of a condenser of capacity C and the current is given as $C\, de = i\, dt$. Starting with these fundamental equations, the Author first investigates the case of a circuit consisting of a resistance, R, and a self-induction L, and finds the well-known expression

$$i = \frac{E}{\sqrt{R^2 + \omega^2 L^2}} \sin(\omega t - \phi),$$

ϕ being the angle of lag, so that $\tan \phi = \frac{\omega L}{R}$.

Denoting by i and e the effective current and electromotive force as defined by last year's Paris Congress, there results

$$i = \frac{e}{\sqrt{R^2 + \omega^2 L^2}}.$$

Passing then to the case of a resistance and condenser C, but no self-induction in circuit, the Author finds that the current at any instant is given by the formula

$$i = \frac{E}{\sqrt{R^2 + \frac{1}{\omega^2 C^2}}} \sin(\omega t + \phi),$$

the lag ϕ, which is defined by the relation $\tan \phi = \frac{1}{\omega C R}$, being in this case negative, that is to say, the current is in advance of the electromotive force. The effective values of current and electromotive force are connected by the formula

$$i = \frac{e}{\sqrt{R^2 + \frac{1}{\omega^2 C^2}}},$$

from which it will be seen that the presence of a condenser reduces the ohmic value of the current, the reduction being, however, the smaller the greater the capacity of the condenser. The lag produced by a self-induction will be equal to the advance (negative lag) produced by a condenser if $w^2 LC = 1$. This consideration leads the Author to enquire whether the lag may become zero if the circuit has both self-induction and capacity. The expression for the current is then

$$i = E \frac{R \sin \omega t + \left(\frac{1}{\omega C} - \omega L\right) \cos \omega t}{R^2 + \left(\frac{1}{\omega C} - \omega L\right)^2};$$

or introducing again the effective current and electromotive force

$$i = \frac{e}{\sqrt{R^2 + \left(\frac{1}{\omega C} - \omega L\right)^2}},$$

which, for $w^2 LC = 1$ obviously becomes

$$i = \frac{e}{R}.$$

In this special case the effect of the self-induction is eliminated by the equal and opposite effect of the capacity. This refers, of course, only to the circuit taken as a whole, but if electromotive-force readings over the terminals of the coil be taken, having self-induction, or over the terminals of the condenser in series with it, very considerable effects may be found. The electromotive-force of self-induction over the coil is

$$e_l = E \frac{\omega L}{R} \cos \omega t,$$

and the electromotive force over the terminals of the condenser is

$$e_c = - E \frac{1}{\omega c} \frac{1}{R} \cos \omega t.$$

For $\omega^2 LC = 1$ these two electromotive forces are equal, but of opposite sign. Each taken by itself will become greater than E, the maximum electromotive force on the terminals of the circuit, if $\omega L > R$, or $\frac{1}{\omega C} > R$. If the resistance in circuit approaches zero the electromotive forces approach infinity. The relation $\omega^2 L C = 1$ can also be written in the form $T = 2\pi \sqrt{L C}$, which is the well-known formula giving the period of the oscillatory discharge of a condenser through an induction coil, when the resistance of the coil may be neglected.

The Author next proceeds to apply this theory to the case of an alternator having an effective electromotive force of 1,000 volts, and a self-induction of 0·2 quadrant. The value of ω he assumes as 500, which corresponds to a frequency of 80. The machine is connected with a concentric cable of practically no resistance and 10 microfarads capacity. The current passing into and out of the cable (the far end being open) will then be 10 amperes. If the machine has a self-induction of 0·3 quadrants the current will increase to 20 amperes and the pressure to 4,000 volts, whilst with a self-induction of 0·4 quadrant the pressure will become infinite and the insulation must break down.

The Paper concludes with the consideration of two parallel circuits, one containing a self-induction and the other a capacity, both circuits being fed from the same source of current.

G. K.

Tests of the Guelcher Thermopile. By F. Uppenborn.

(Elektrotechnische Zeitschrift, 1890, p. 434.)

This thermopile was described on page 187 of the Elektrotechnische Zeitschrift, and since then the following tests have been made.

1. *Electromotive Force.*—This depends on the consumption of gas. After lighting the flame the electromotive force of the pile reached its maximum in ten minutes. A diagram of the electromotive force as a function of time is given which shows that the curve rises rapidly, so that in ten minutes the pile is ready for use. The relation between electromotive force and gas consumption per hour is as follows:

Gas.	Electromotive Force.
7·57 cubic feet	3·64 volts.
8·80 „	3·90 „
9·08 „	3·97 „

8·80 cubic feet per hour is the maximum consumption allowed; if more be used, the pile may be injured. A special test had to be made for polarization. The pile was short-circuited, and after removal of the short circuit the electromotive force was 0·1 volt lower, but rose to the normal figure again before the torsion galvanometer had come to rest.

2. *Resistance.*—The determination of the resistance by means of a Siemens universal galvanometer, in consequence of the polarization of the pile, gave uncertain results while the resistance appeared to be at least 0·39 ohm. The resistance of the pile while warm could be ascertained with sufficient accuracy from the electromotive force and current by the insertion of a known resistance in the outer circuit. From earlier experiments on another thermopile the Author has ascertained that accordant values can be obtained by inserting different resistances in the outer circuit, thus showing that the polarization is small while hot. Professor von Wattenhofen has shown that polarization occurs in cold thermopiles just as in voltameters. When using 7·57 cubic feet of gas per hour the internal resistance appears to be 0·48 ohm; with a consumption of 8·8 cubic feet the resistance is 0·46 ohm. From these observations it appears that the resistance of the warm pile does not diminish materially with an increase in gas consumption or temperature; on the other hand, the resistance of the cold pile is less. It would appear as if the resistance, therefore, at first increases as the heat rises, and reaches a maximum and decreases again as the alloy reaches the point at which it begins to soften.

3. *Useful Effect.*—The maximum useful effect of a thermopile is reached when the outside resistance is equal to the internal resistance. If, therefore, the internal resistance be taken as w, and the electromotive force as E, the maximum useful effect is $\frac{E^2}{4w}$. The useful effect of the thermopile in question was with a consumption of 7·57 cubic feet of gas per hour; 6·83 watts, or 1 watt per 1·1 cubic foot of gas used, and with a consumption of 8·8 cubic feet of gas per hour, 8·22 watts, or 1 watt per 1·07 cubic foot of gas used. In addition to the above details the following were given to the Author by Mr. Guelcher. Latterly the alloy used has not proved so good as it was formerly, so that the efficiency of the piles has been lower. The production of the alloy is the most difficult point. The variation proceeds mainly from the variable nature of the raw material used, and attempts to obviate this difficulty by the use of chemically pure materials have not so far been successful, not so much on account of the increase in cost, which, however, would be considerable but from the fact that the ores from certain mines give better results than the pure materials. The most troublesome feature in the manufacture is that the specific resistance of the alloy fluctuates greatly between the limits 14·4 and 36·6; for this reason all the separate elements of a pile are tested before being put together, and those having a higher resistance than 0·01 ohm are rejected, so that the working resis-

tance of a pile of 50 elements cannot exceed 0·5 ohm; the lowest resistance of such a pile yet attained was 0·356 ohm. It is hoped that partly by better methods of melting and alloying, and partly by using steel cases instead of brass to unite the alloy to the nickel tubes that the difficulties of manufacture will be overcome. Tests are made of every pile before it leaves the factory, and a table is given of some of the results obtained. The Author states that when he paid a visit to the works of Julius Pintsch, he inspected an apparatus for depositing nickel which was worked by two Guelcher thermopiles. He states that the work was well done, and that the heavy and inconstant Bunsen batteries previously in use had been done away with.

E. R. D.

On Two Forms of Electrical Gyroscopes, to demonstrate the Movement of the Earth, and for the Correction of the Mariner's Compass. By G. Trouvé.

(Comptes Rendus de l'Académie des Sciences, Paris, vol. cxi. 1890, p. 357.)

For the former purpose the instrument is constructed of a small radial pole electro-magnetic motor, forming as it were the skeleton of the gyroscopic fly-wheel; the whole being covered first with a special cement, and then electrotyped with copper about ⅛-inch thick, carefully balanced and turned up in the lathe so that the appearance is exactly that of the ordinary metallic gyroscope; the field in which this armature rotates is a soft iron ring with two snail-shaped poles diametrically opposite. The whole motor is suspended by a fine wire; and the current, brought to it by two wires dipping in concentric mercury cups, causes it to rotate at 300 to 400 times per second.

For the latter purpose a similar motor of more massive construction is mounted in gimbals, and when set in motion preserves a constant plane of rotation during a time sufficient for the determination of the compass deviation while the ship is swung in the usual way.

F. J.

An Electric Travelling-Crane.

(Railway Master Mechanic, U.S.A., November 1890, p. 187.)

An illustration represents an electric crane lifting 50 tons of rails. It is used in the erecting department of the New United Pacific car shops at Cheyenne, W.T. It travels the whole length of the building, and has a span of 55 feet. The heavy iron I-beams which carry the 75-lb. rail on which the crane runs are supported by wooden columns capped with iron. On each side are two

grooved wheels 30 inches diameter. The two crane-girders are 4 feet apart. The two trolleys, weighing 8 tons each, run on a light track on the girders. Five motors are used, one for the crane as a whole, and two for each trolley. The operator's cage is suspended from one end, and contains the switch board where, by means of a sliding copper tube, connection is made with the two copper wires from the dynamo which run on the inside of the beam. From the board wires run to the crane motor, and also a set of wires for each trolley along the inside of the girders. The motor, by means of gearing, turns the shaft which runs on the outside of the length of the crane, and which, by means of a pinion on each end turns a spur wheel on the axle, carrying the crane wheels, thus giving the motion of the crane up and down the shop. Each trolley works independently of the other, and each has two pairs of wheels 18 inches diameter, 5 feet apart, and each carries two drums 3 feet 6 inches long by 2 feet diameter, which both wind or unwind simultaneously. There are two brakes, one for safety in case the other fails. The whole apparatus is operated by five levers; one for each motor, both motions of any part being accomplished with one lever by moving it in opposite directions from the centre. The crane is said to give no trouble, and is rated at 40 tons capacity, but was tested by raising a load of 50 tons of rails, and is used to lift engines off their driving wheels. It was built in Milwaukee by the Shaw Electric Crane Company.

E. R. D.

Methods of Estimating the Carbonic Acid present in the Atmosphere. By Dr. H. Bitter, of Breslau.

(Zeitschrift für Hygiene, vol. ix. 1890, p. 1.)

The process of Pettenkofer, based on the determination of the volume of carbonic acid gas present therein, still remains the safest means of judging of the quality of the air in dwellings. All attempts to substitute some other method of estimation must so far be pronounced failures. Even the plan suggested by Uffelmann, of calculating the amount of organic substances in the atmosphere, has this defect, that we are unable to ascertain which of these substances are of a toxic nature, and are therefore injurious, while a knowledge of the amount of carbonic acid gas contained therein is a certain indication of the measure of the deleterious substances present. The method of testing for carbonic acid gas devised by Pettenkofer, is the surest and best mode of analysis, but many simpler and more expeditious processes have been suggested in recent years. Certain objections have from time to time been formulated with respect to the results obtained by Pettenkofer's process, and before adopting this as the standard by which to test the results attainable by other systems of analysis, the Author undertook a careful inquiry into these supposed sources

method of Pettenkofer. In the course of these experiments, the Author somewhat modified the form of the apparatus, and the modifications are explained by reference to a diagram. Having established a system of analysis capable of yielding very accurate results, the Author conducted comparative tests, which are set forth in a series of tables, of this apparatus, and of the methods advocated by Hesse, Fossek, Lunge, Wolpert,[1] Blochmann,[2] Nienstaedt and Ballo, Wolpert (continuous),[3] Shaffer, and several others. Many of the contrivances were found to give wholly unreliable values for carbonic acid; the process of Lunge is preferred, where great accuracy is not needed, as being readily applicable and capable of being carried out by persons not skilled in chemical manipulations. A modified form of the system introduced by Nienstaedt and Ballo, wherein a given volume of air enclosed in a vessel is agitated with a liquid re-agent added in small quantities at a time, until a change is produced in the colour of a solution of phenolphtaleïn, is described and illustrated by the Author. The apparatus is one capable of yielding very accurate results, and it is of such a construction as facilitates, if needs be, its transport to a distance.

G. R. R.

The Apparent Thickness of Oil-Films on Water. By L. Sohncke.

(Annalen der Physik und Chemie, vol. xl., 1890, p. 345.)

If a very small drop of oil is placed upon a surface of water in a sufficiently large dish it spreads out rapidly at first and then separates into small disks. In a very small capsule the oil film may extend to the edges and remain constant, but in one of an intermediate size the continuous film breaks when the oil has nearly reached the edge, and the phenomenon takes place slowly, and can be more easily observed than in the first case. As the tint of the film is uniform, and the rupture takes place simultaneously over the entire surface, the thickness must be constant, so that it is only necessary to weigh the drop of oil and measure the diameter of the film to determine the thickness of the latter.

The weight may be obtained by suspending below the pan of a very sensitive balance a fine aluminium wire plunged in oil, and weighing it before and after contact with the water. In a second series of experiments the height of the suspended drop at the end of the wire was measured by a micrometer microscope, but the values so obtained were smaller than those obtained by the former

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[1] Minutes of Proceedings Inst. C.E., vol. lxxxiii. p. 551.
[2] *Ibid.*, vol. lxxxi. p. 384.
[3] *Ibid.*, vol. lxxxviii. p. 518.

method, and were not used; because a further quantity of oil was observed to flow down the wire after the contact.

The diameter of the spot of oil, which was observed with a divided scale placed at the bottom of the capsule, can only be determined with difficulty on account of the rapidity of the phenomenon, and may be in error to the extent of 10 per cent. of the total surface. The duration of the experiment is too short for it to be sensibly affected by the oil dissolving on the water.

The results obtained were

For olive oil $e = 111 \cdot 5 \pm 7 \cdot 04$ millionths of 1 millimetre.
For colza oil $e = 93 \cdot 9 \pm 6 \cdot 82$ „ „

As the radius of molecular action must be equal to or larger than e, we obtain in the first case

$$\rho \gtreqless 55 \cdot 70$$

and in the second

$$\rho \gtreqless 46 \cdot 80$$

which figures are of the same order of magnitude as those found by Plateau for liquids of the class of glycerides.

H. B.

Ventilation of a Weaving-Shed. By L. Perreau.

(Compte rendu de la Société des Ingénieurs-civils, Paris, August, 1890, p. 293.)

The positive disadvantages of the want of pure air in large buildings have been statistically demonstrated by the Author, who was engaged to provide apparatus to effect the ventilation of a weaving-shed at Lisieux, holding three hundred and sixty looms for the manufacture of household linen, and employing four hundred persons. The shed is on the ground level, and is 201 feet in length by 108 feet wide, and about 11 feet high in the clear. It is divided into seventeen bays, roofed with rough boarding. The northern aspect is glazed; the southern is slated. The floor-area is about 22,000 square feet, or say, 55 feet per head; the capacity about 212,000 cubic feet, or 530 cubic feet per head. The shed is warmed in winter by low-pressure steam, which circulates in 6¼-inch horizontal copper pipes. These pipes are supported by the columns at a level of about 1 metre above the highest looms. They have a total heating surface of 1,612 square feet, or 1 square foot for each 13·3 square feet of floor-area.

The volume of air to be delivered and withdrawn was fixed at 30 cubic metres, or 1,060 cubic feet per hour per head; in all ($30 \times 400 =$) 12,000 cubic metres, or 424,000 cubic feet per hour, or 3·33 cubic metres or about 118 cubic feet per second. Since the application of heating-apparatus the volume has been increased to

derived from a small jet of water forced under high pressure into each entrance for air, and pulverized to promote absorption. The vitiated air passes off into channels under the floor, whence the currents are collected and conveyed to the factory chimney, which is 49·4 square feet in sectional area, and 177 feet in height—large enough for the ordinary draught from five steam-boilers together with the draught of vitiated air. A partition wall 13 feet high, at the foot of the chimney, provided for the free entrance of the currents into the chimney without interfering with each other. The temperature in the chimney, when 2,200 lbs. of coal—the usual quantity—are consumed per hour varies from 430° Fahrenheit to 460° Fahrenheit.

Since the ventilating apparatus was put in regular operation, the health and appetites of the work-people have materially improved. Production has been augmented between 6 and 7 per cent. in consequence of the greater energy and activity of the work-people.

D. K. C.

INDEX

TO THE

MINUTES OF PROCEEDINGS,

1890–91.—Part I.

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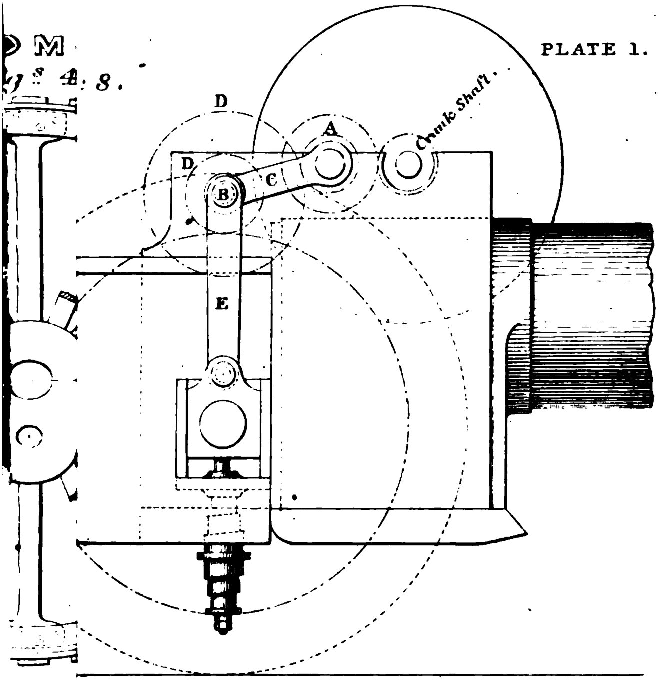
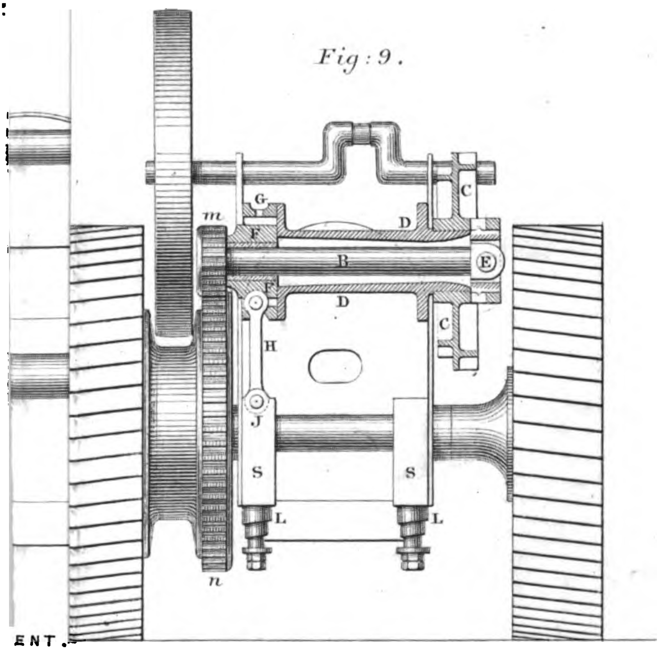
STAMFORD STREET AND CHARING CROSS.

Figs 4 : 8.



RIM.
PLAWLER & Co's ARRANGEMENT OF SPRINGS.

Fig : 9.



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MESSRS BURRELL & SON'S SPRING ARRANGEMENT.

THOS KELL & SON, LITH. 40, KING ST COVENT GARDEN